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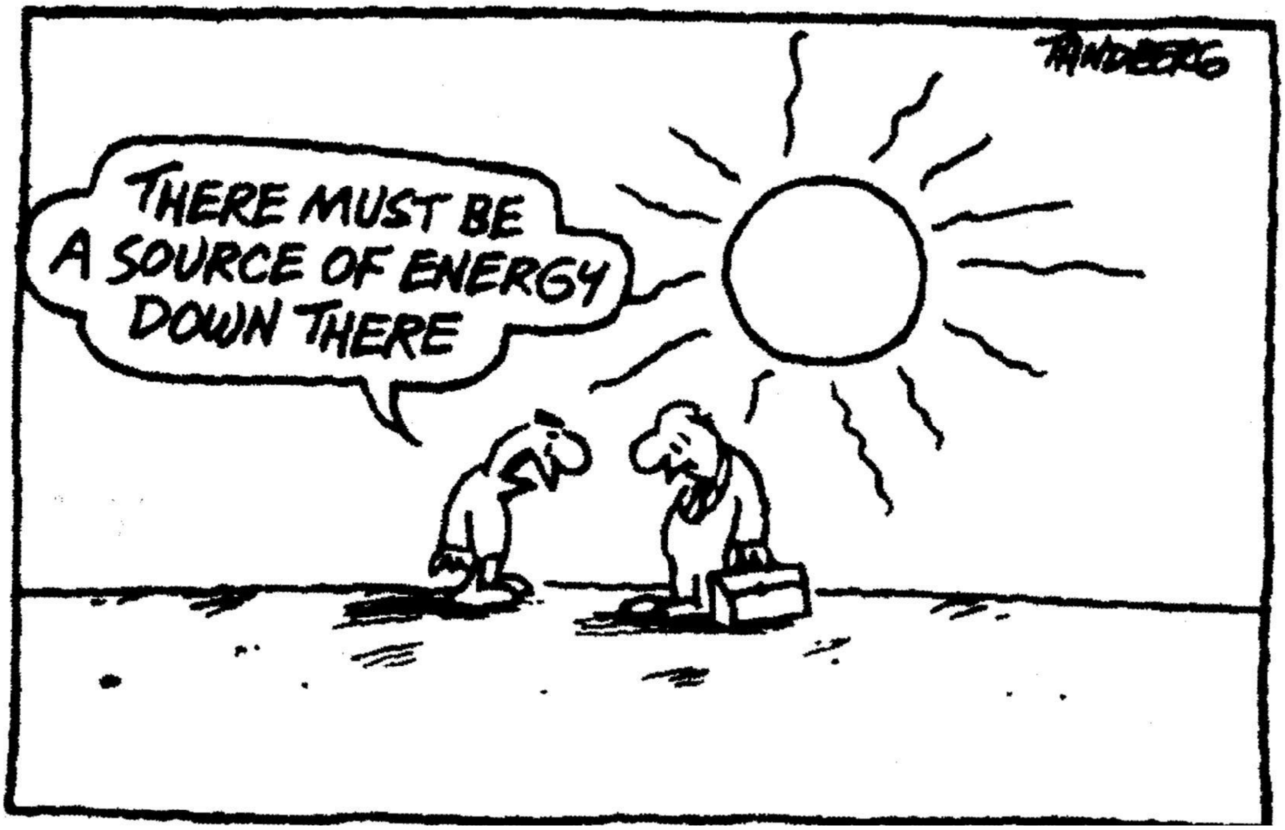

Investigation of the Potential of Rice Husk-based Power Plants and a Pre-feasibility Assessment of Possible Plants in the An Giang Province, Vietnam

Master of Science Thesis in the Master's Progam in Industrial Ecology

TRANG THU NGUYEN

Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2014

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Cover: Cartoon “There must be a source of energy down there!”, drawn by Australian cartoonist Ron Tandberg

Printed by:
Chalmers Reproservice
Göteborg, Sweden 2014

Abstract

Biomass currently covers approximately 10% of the global energy supply. Rice husk is an agricultural biowaste having potential for power generation. In the An Giang Province, an important location for rice production in the Mekong Delta region in Vietnam, there is a high possibility for thermal power plants using rice husk. However, their feasibility in term of technology, socio-economy, and environmental benefits, needs to be investigated thoroughly.

This study aims at (1) providing information of the current status of rice husk-related issues (e.g., logistics, market and price, current uses) in An Giang, (2) investigating the reasons why a rice husk-based power plant built in another location failed to generate electricity, and (3) producing a pre-feasibility assessment of two possible power plants owned by two selected rice mills which are likely to be constructed at their sites in the future.

To answer these questions, a field trip was carried out in Vietnam for 7 weeks. 38 rice mills in An Gang were interviewed to obtain current status of rice husk at the local business level. Questionnaires and interviews with experts from the Institute of Energy in Vietnam, the Department of Environment and Natural Resources in An Giang, representative sof the Vietnam Electricity (the state-owned company, EVN), and the unsuccessful power plant fueled by rice husk in Can Tho Province were conducted. Site observations were also part of the investigation at the mills and the power plant. In addition, four rice mills were surveyed in detail, to prepare for a pre-feasibility study for two selected plants. The collected data was processed by using data analysis and pre-feasibility assessment methods.

The results show that the current status of rice husk in An Giang reflects changes in several areas such as markets and policy in recent years in Vietnam. Rice husk has become a traded commodity producing profits to its rice mills and is used as fuel for drying systems or sold as raw material or in the form of briquettes, thus it is not wasted. Rice husk-based power plants may be more suitable at bigger scale rice mills. The investigation shows that low profit is the main cause of the failure of the unsuccessful power plant identified in Can Tho.

The pre-feasibility assessment shows that most profitable solution for the studied rice husk-based power plants is that they are scaled to satisfy the energy demand of their own rice mill, and not to sell excess power to the grid. It is also discussed that combusion technology is most suitable to both studied power plants, with capacities of 670 kW and 580 kW, respectively. Carbon credits contribute only a minor share of the power plant's profitability. Yet this may change if the CERs price increases in the future.

Key words: rice husk, biomass, pre-feasibility, combined heat and power, power plant

Acknowledgement

First of all, I would like to express my deepest thanks to my supervisor, Dr. Erik Ahlgren at Chalmers University of Technology, for his initiation of this thesis project, as well as his great guidance during the time the study was conducted. Moreover, his contacts at the collaboration project between Vietnam and Sweden, and Institue of Energy in Hanoi, Vietnam were a big help to collect data via the field trip in Vietnam.

I also would like to thank Dr. Tuan Nguyen, Head of International Cooperation at Institute of Energy in Hanoi, Dr. Van Ha, Dean of Department of Natural Resource and Environment at University of Natural Resources and Environment in Ho Chi Minh City, Mrs. Ngoc Xuan Pham, Head of Environmental Protection Office, Department of Natural Resources and Environment in An Giang Province, Mr. Dinh Hai Truong, Director of Dinh Hai Thermal Power Company in Can Tho Province, and Mr. Minh Hai Nguyen, Chief Supervisor of EVN HCMC for their responses that are valuable data for the input of the study.

In addition, I am extremely grateful for the important support and help on interviews with rice mill owners in An Giang that I have gotten from Miss Thanh Thao Vo Nguyen at Agirbank Ho Chi Minh City and Mr. Thanh Quang Ngo, Chief Accountant at Phu Vinh Food Company in An Giang, as well as several local assisstants. Without their help, the data collection at the rice mills would be hard to carry out.

Furthermore, I am greatly thankful for all the valuable comments that I have received from Björn Kjellström, an expert who is taking part in the collaboration project. His remarks and opinion contribute a great deal to improving the quality of the assessment.

Last but not least, my greatest gratitude goes to my family and friends, who have been encouraged me continously during my journey of two years in the Master's programme. They are, as always, my driving force in life.

Göteborg, June 2014

Trang Thu Nguyen

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Abbreviations

APEC:	Asia-Pacific Economic Cooperation
CDM:	Clean Development Mechanism
CHP:	Combined Heat and Power
CIA:	Central Intelligence Agency of United States
DHTPC:	Dinh Hai Thermal Power Company
ESRU:	Energy Systems Research Unit, University of Strathclyde Glasgow
EVN:	Vietnam Electricity
FAO:	Food and Agriculture Organization of the United Nations
GAIA:	Global Alliance for Incinerator Alternatives, Global Anti-Incinerator Alliance
GRiSP:	Global Rice Science Partnership
GSO:	General Statistics Office Of Vietnam
ha:	Hectares
HPR	Husk to paddy ratio
HRSG	Heat recovery steam generator
ICE:	Internal Combustion Engine
IEA:	International Energy Agency
IRENA:	The International Renewable Energy Agency
IRRI:	International Rice Research Institute
IZ:	Industrial Zone
KW_e:	kW electricity
KW_{th}:	kW thermal energy
MDR:	Mekong River Delta
Mtoe	Million Tonnes of Oil Equivalent
NNFCC:	The Bioeconomy Consultants, United Kingdom
NREs:	New renewable energy sources
PFS:	Pre-feasibility Study
PREGA:	Promotion of Renewable Energy, Energy Efficiency and Greenhouse Gas Abatement
RECIPES:	Project on Renewable Energy in Emerging and Developing Countries
RRD:	Red River Delta
SFC:	Specific fuel consumption
UNEP:	United Nations Environment Programme
UNFCCC:	United Nations Framework Convention on Climate Change
USD:	US dollars
VND:	Vietnamese Dong
WADE:	The World Alliance for Decentralized Energy
WB:	World Bank

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1. Introduction

Biomass is a flexible raw material that can be utilized for producing power, heat, bio-fuels, and bio-products. Considered as a carbon-neutral bearer when it is produced and used on a sustainable basis, biomass can contribute a large part to reducing greenhouse gas (GHG) emissions (IEA, 2007). Currently, approximately 10% of the global energy supply is covered by biomass. About two thirds of the energy use of biomass, namely 34 EJ/year, took place in developing countries for heating and cooking. In 2009, about 13% of biomass was consumed for heat and power generation (Vakkilainen, et al., 2013). Electricity generation from biomass has been considered as a promising method to utilize this resource.

As a result of intensive agriculture due to population growth and improved living standards, waste argicultural biomass has been increasing, in term of both volume and types. As rotten waste agricultural biomass emits methane and leachate, while open burning by the farmers generates CO2 and other local pollutants, improper management of these biowastes, hence, is creating negative impacts on climate change, water and soil contamination, as well as local air pollution. On the other hand, this waste is of high value when it comes to material and energy recovery (UNEP, 2009).

Every year, 140 billion tonnes of biomass wastes[1] is generated from agriculture all around the world, equivalent to approximately 50 billion tonnes of oil. Conversion of agricultural biomass waste into energy can substantially displace the use of fossil fuel, therefore reduce GHGs and provide renewable energy to some 1.6 billion people in developing countries (UNEP, 2009).

Vietnam, a developing country locates on the Indo-China Peninsula, is the 14th-most-populous country in the world with nearly 90 million inhabitants. About 70% of the population lives in rural area (CIA, 2014), and approximately half of the working-age population takes part in the agricultural sector (GSO, 2013). Since 1986, the country has been transitioning from the inflexibilities of a centrally-planned economy to a more opened status. Vietnamese government has reaffirmed its commitment to economic modernization in recent years, with it joining the World Trade Organization in January 2007, which has promoted more competitive and export-oriented industries (CIA, 2014).

The economic development of the country has led to increasing its energy demand. In Vietnam, the electricity mix includes various types of power generation, such as coal, hydro, natural gas, and oil (EVN, 2013). With a vision towards 2020 and 2030, Vietnamese government plans to utilize and expand the proportion of renewable energy (Mayer Brown-JSM, 2011). Possessing an abundant resource of biomass, Vietnam has been paying more and more attention on this energy resource. Due to the fact that Vietnam is one of the dominant rice producers, as well as exporters, rice husk is considered as a promising energy supply.

[1] Biomass wastes include agricultural wastes, such as corn stalks, straw, sugarcane leavings, bagasse, nutshells, and manure from cattle, poultry, and hogs; forestry residues, such as wood chips, bark, sawdust, timber slash, and mill scrap; municipal waste, such as waste paper and yard clippings (UNEP, 2009)

Located in Mekong Delta River, An Giang province is one of the most important areas for rice production in Vietnam. Thus, it possesses high potential of utilizing rice husk for energy generation. With more than 1000 rice mills operating in the region, most of them are at small and medium-scale, and based on the local characteristics, there is a need for assessment of rice husk-based power production at business level.

In light of the recently issued Decision on March 24th 2014 by Vietnamese authorities, biomass-based energy now will be supported by a mechanism. Definitely, this is going to contribite to the development of power plants fueled by biomass, particularly rice husk in this case. Carbon credit trading under the Clean Development Mechanism also provides a profit for the power plants, which may have a significant effect on their feasibility. In addition, possibility of competititon in use for rice husk can happen in the near future, with another project that plans to build 20 power plants fueled by this argo-residue in Vietnam.

1.1. Aims and research questions

An Giang Province possesses a high possibility for thermal power plants using rice husk at business level. However, their feasibility in term of technology and socio-economy, as well as environmental benefits, needs to be investigated thoroughly.

This research, therefore, aims at (1) providing information of the current status of rice husk-related issues (e.g., logistics, market and price, current uses) in An Giang, (2) investigating the reasons why a rice husk-based power plant built in another location failed to generate electricity, and (3) producing a pre-feasibility assessment of two possible power plants owned by two selected rice mills which are likely to be constructed at their sites in the future.

1.2. Boundaries

The geographical boundary covers An Giang province in Vietnam. An Giang province has one city (Long Xuyen), one provincial town (Chau Doc) and 9 districts (Chau Phu, Chau Thanh, ChoMoi, Phu Tan, Tinh Bien, Tri Ton, Tan Chau, Thoai Son and An Phu), all of which are considered as target regions in this study.

The temporal boundary is defined from the point when the study conducted, which means spring 2014 to the next 20 years (till 2034) as it assumed to be life time of the possible power plants.

In term of system boundaries, in this research technical solutions are assessed in general terms, especially the options of equipments. For carbon emission reduction, it is obtained only by the replacement of electricity generated from rice husk with electricity generated from fossil fuels. This study neglects the carbon emissions that probably appear from the fact that when the part of rice husk which normally sold to use for other purposes in other places, now is utilized for power generation. As a consequence, those places would need to have alternative energy resources to replace the amount of energy taken from the rice husk. Depending on the alternative options, CO_2 emission may be emitted.

1.3. Delimitations and limitations

This research is delimited by several barriers as described below.

- This research does not look at complete technical systems of the rice husk-based power plants, only at the main components instead. Proposed technical solutions are therefore in general term.

- Price of CERs will be assumed to stay the same as at the moment.

- The changes in price of different parameters will not be taken into account, except for that of CERs. Thus, sensitivity analysis will only be considered for CERs.

- Only rice husk will be considered as fuel at the power plants.

- In term of economic evaluation, only NPV and payback period will be used to determine the profitability of the cases.

- The capital needed for investment is thought of being available for the investor.

- There will be no risk assessment for investment.

- Because CO_2 emission which may appeared in other places due to the replacement of rice husk, is considered beyond the boundaries of the reasearch, the results on environmental aspects are not comprehensively evaluated.

1.4. Structure of the report

The report consists of seven chapters. The introduction provides brief information about the study, research questions, boundaries, and limitations. Basic knowledge of rice, rice husk and rice husk based energy conversion, as well as short description of Vietnam, An Giang province, the Clean Development Mechanism, and the energy policy in Vietnam will be mentioned in Chapter 2. The next chapter describes methodology used in this research, concerning the field trip, data processing and pre-feasibility assessment.

Chapter 4 shows the results which answer the first two research questions, namely the current status of rice husk-related issues in An Giang and findings from the investigation at the unsuccesful power plant. Meanwhile, Chapter 5 addresses the pre-feasibility study of the two possible power plants fueled by rice husk.

The following chapter discusses about the results, with consideration for other project of the same kind in the horizon. Based on results and discussion, conclusion can be found in Chapter 7. In addition, the Annex provides translations of all the questionnaires used in the field trip.

2. Background

This section provides an overview and general knowlegde about rice and rice husk, rice husk-based energy conversation techonologies, Vietnam and the studied province, as well as the Clean Development Mechanism (CDM) and Vietnamese energy policy, which are all relevant topics to this reasearch.

2.1. Rice

Rice farming is the largest single use of land for producing food. As of 2010, more than 700 million tonnes of rice is produced worldwide every year, of which 90% is produced in East, South and Southeast Asia. In 2012, worldwide rice production totalled 720 million tonne (FAO, 2014). It is one of the most important economic activities on Earth with thousands of varieties of rice are farmed. Only 7% of all rice production is exported from its country of origin to other places (GRiSP, 2013).

Rice provides a staple nutriment that makes the basis of the traditional diet of a large proportion of the human population (Abbas & Ansumali, 2010). It is the source of one quarter of global per capita energy. Especially throughout Asia, rice is synonymous with food, making it the most consumed cereal grain. This agricultural product is also the most important food grain in most of the tropical areas of Latin America and the Caribbean, where it supplies more calories in people’s diets than wheat, maize, cassava, or potato (GRiSP, 2013).

2.1.1. Paddy grain

Figure 1 illustrates components of a paddy grain. Basically paddy grain consists of a husk and a grain of brown rice. Brown rice contains a bran layer (including pericarp, seed coat, and aleurone layer), a germ and scutellum connected on the ventral side of the grain, and an edible portion or endosperm.

Basically, paddy grain is not yet suitable for eating. It becomes eatable only if the husk and the bran are removed. The removal of the two parts can be done in the milling process (Le, 2003).

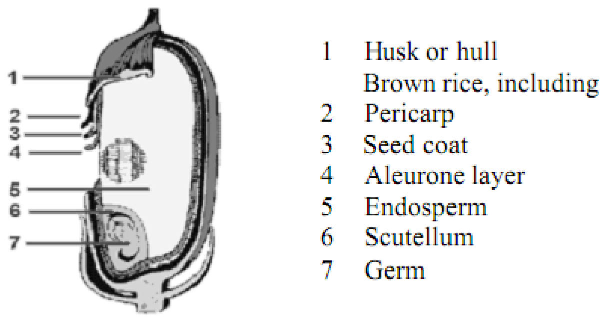


Figure 1: Paddy grain (Le, 2003)

2.1.2. Rice milling

Rice milling is the process of removing the husk and the bran layer to produce the edible portion for consumption. Rice milling process embraces two basic phases. Firstly the husk is removed to produce brown rice by the operation called dehusking or dehulling. The other phase is the removal of the bran layer from brown rice to produce polished or white rice; this is called polishing or whitening. Milling also removes the germ and a portion of the endosperm as broken kernels and powdery materials (Le, 2003).

There is various techniques for rice milling. A suitable technique should be taken investment costs and technical efficiency, i.e., loss in milling, into account. In principle, more costly techniques in terms of investment cost per ton of milling capacity tend to be more efficient in terms of generating lower loss, both quantitatively and qualitatively. Cheaper milling techniques have advantages regarding to smaller investments but at the same time result in high milling losses (Le, 2003).

2.1.3. Rice husk

Rice husk is a by-product of the rice milling process. Rice husk has a number of names, the most common being husk, hull, and chaff (Pte-Ltd, 2014). With the husk to paddy ratio (HPR) is estimated to range between 0.2 – 0.22 (Abbas & Ansumali, 2010), global production of this biowaste is very significant, approximately 150 million tonnes per annum to be specific. Typically, roughly 50% of the husk produced in a rice mill is burned on-site for steam generation to drive the mechanical milling machinery. The remaining part is sold to other industries, especially to silica-based factories and business, or utilized in building materials and as fertiliser (Abbas & Ansumali, 2010).

The characteristics and chemical content of rice husk are displayed in Table 1 and 2 below. Rice husk contains 75-90% organic matter such as cellulose, lignin, and rest mineral components such as silica, alkalis and trace elements (Kumar, et al., 2012). Because of the high energy capacity of rice husk (two barrels of oil equivalent by one rice husk tonne) a large amount of rice husk has been used as bio fuel to power boilers, producing steam for drying and the parboiling process. Due to its low bulk density (90-150 kg/m^3) (Hwang, et al., 2011), this agro-residue has a large dry volume, and as a consequence, most rice husk can be made into pellets or briquettes to save storage space and transport the biowaste economically.

Table 1: Technical characteristics of rice husk (PREGA, 2004)

Characteristics	Value
Moisture content %	8.84
Volatile matter %	57.95
Ash content %	15.24
Fixed carbon %	18.64
High heating value kcal/kg	3800

Table 2: Chemical contents of rice husk (PREGA, 2004)

Characteristics	Value
C (%)	31.65
H (%)	6.12
O (%)	36.08
N (%)	1.87

Different applications of rice husk depend upon its physical and chemical properties. For example, direct use of this argo-residue as fuel has been seen in power plants. Due to its characteristics only a small proportion of rice husks has been utilized for non-energy related low value applications, such as chicken litter, animal roughage, mulching and bedding materials. Besides, rice husk finds its use as source raw material for synthesis and development of new phases and compounds. So far in many Asian countries, where the bulk of rice is produced and consumed, a major proportion of the husk in carried to open areas for disposal by burning (Bonten & Wösten, 2012).

The production of rice husk is expected to increase. Figure 2 presents the historical trend of rice production for the last 45 years. As it can be seen clearly, an increasing production trend that can be correlated with the world's increasing population is depicted on the graph. The calculated trend for quantity of rice husk represents an increase of around 1.5% per annum (Abbas & Ansumali, 2010).

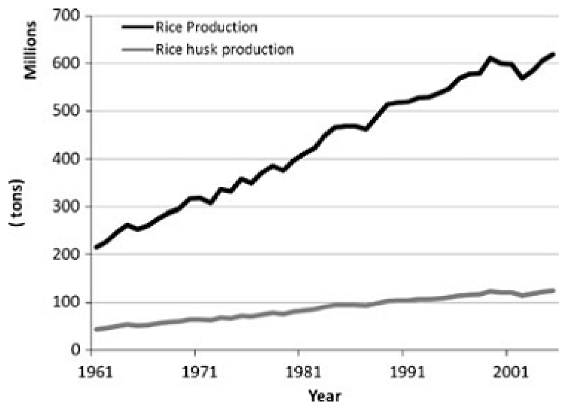


Figure 2: Historic trend of the world rice production and the calculated world rice husk output (Abbas & Ansumali, 2010)

2.1.4. Rice ash

Compared to other biomass fuels, rice husk is unusually high in ash with the content being between 10-20%. The ash is 87-97% silica, highly porous and light weight, with a very high external surface area (Kumar, et al., 2012). The abrasive character of the husk is due to the ash composition and structure that containing a high concentration of silica (IRRI, 2014). This feature also makes rice husk ash a valuable material for use in industrial application (Kumar, et al., 2012). The ash properties vary due to the differences in incinerating conditions, rate of heating, geographic location, and fineness. Highly reactive ash is obtained when rice husk is burnt under controlled conditions. This compound contains a high silica content in the form of non-crystalline or amorphous silica of up to 95% (Hwang, et al., 2011).

The utilization of rice husk ash as a pozzolanic material in cement and concrete provides several advantages, such as improved strength and durability properties, reduced materials costs due to cement savings, and environmental benefits related to the disposal of waste materials and to reduced CO_2 emissions (Bui, et al., 2005).

Rice husk ash is a carbon neutral green product. Lots of ways are being thought of for disposing them by making commercial use of this biowaste, such as in green concrete, refractory, ceramic glaze, insulator, roofing shingles, waterproofing chemicals, oil spill absorbent, specialty paints, flame retardants, carrier for pesticides, insecticides and bio fertilizers (N.K. Enterprises, 2014).

2.2. Utilization of rice husk for energy purposes

Rice husk is defined as renewable energy resource which can be used to mitigate greenhouse gas (GHG) emissions. Conversion of rice husk into heat, steam, gas or liquid fuels would benefit countries that have no traditional energy resources and have an abundant supply of this agro-residue. Promoting the use of rice husk for the energy sector would mitigate local environmental problems, e.g., rice husk dumping and open burning, and highlight the benefits of GHG reduction to the community and environment (Pham, et al., 2011).

In Asian countries, rice husk is partly used as an energy source for processes in the rice production, some other parts as an energy source for cooking, heating and other uses as well as soil ameliorator. It is estimated that worldwide 38 to 57 million tonnes of rice husk is available for energy generation. Due to its low density, transportation of rice husk is relatively expensive. It is therefore interesting to consider the option of generating heat and/or power on-site at rice mills where the husk is available and cost for transportation can be minimum. A processing capacity of at least 100 tonne rice per day is considered to be essential to turn a rice mill into an interesting source of rice husk for the production of these energy forms (Bonten & Wösten, 2012).

2.3. Rice husk-based energy conversion technologies

The flowchart below (Figure 3) maps out various conversion processes down to energy products. It can be used as a guide to end-users on which technology to consider given their desire for energy product. Furthermore, Figure 4 shows the level of use of various conversion technologies for energy. According to it, household energy, mainly for cooking, heating and drying, are the most widely available technologies. It has been reported that biomass cook stoves, for instance, have hundreds of versions all around the world, with a lot of existing samples in the Southeast Asia. Meanwhile, gasification and pyrolysis have most technologies in the demonstration stage. These technologies are concentrated in Europe, USA, Japan and India. Bio-oil and bio-chemical applications are mostly in the research and development stage and are distributed in Europe, North America and Japan (COGEN 3, 2003).

Co-generation of heat and power has been used for decades in various industries such as food processing, wood, textiles, pulp and paper, chemical, petrochemical industries and others. An increasing trend is seen in the applications of co-generation in not only these conventional fields, but also in industrial estates and in buildings to cover the heat and/or cooling requirements. Having high energy requirement, these sectors represent a large market for co-generation technology (COGEN 3, 2003). In comparison with conventional generation, combined heat and power (CHP) systems have higher overall efficiency, and reduce much more losses during opereration, as indicated in Figure 5.

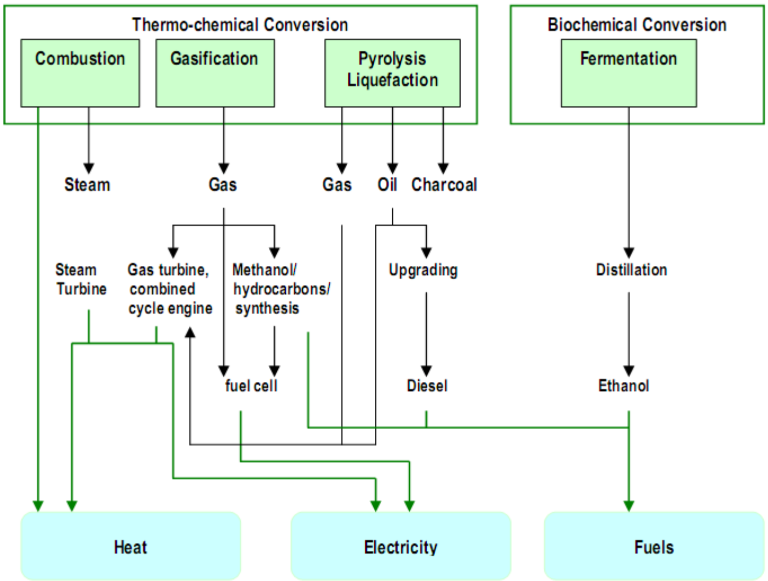


Figure 3: Conversion Routes for Cellulosic Agricultural Biomass Waste (UNEP, 2009)

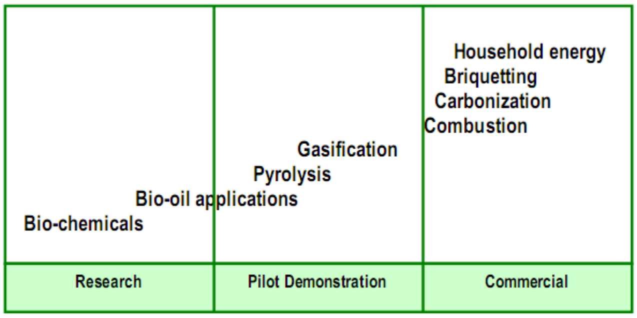


Figure 4: Level of use for energy conversion (UNEP, 2009)

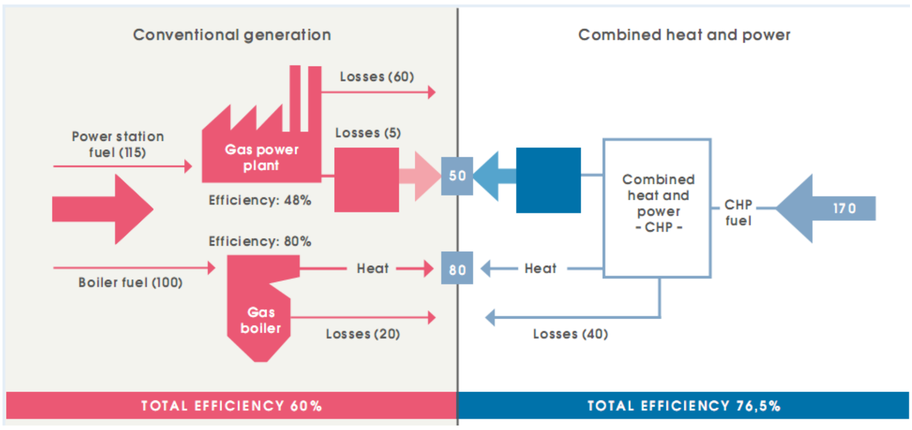


Figure 5: Comparison of conventional generation and CHP (IRENA, 2012)

The process of generating energy can be divided into primary source, fuel preparation, handling and storage, conversion methods and power generation. Table 3 shows a vast array of heat and power based generation technologies for biomas. As can be seen, there are many biomass fuel transformation methods, as well as possible conversion process alternatives. However, it is worth to note that plenty of these technologies are not fully proven or commercial in nature (COGEN 3, 2003).

Primary conversion methods include combustion (direct conversion to heat), gasification/pyrolysis (conversion to product gas, methanol, ethanol, poyrolysis oil or bio-oil), and biochemical (conversion to biogas, ethanol).

Direct combustion has been reported to be the established and well-proven method for converting biomass to heat. Gasification, on the other hand, is considered a more complex method, which is proven for small-scale units, while medium scale and advanced systems are still in demonstration phases. Pyrolysis has reached a near commercial status. Bio-chemicals in the form of anaerobic digestion albeit still fairly new, which is also commercially available (COGEN 3, 2003).

Table 3: Energy conversion technologies for biomass (COGEN 3, 2003)

PRIMARY SOURCE		REFINEMENT	FUEL	CONVERSION		POWER GENERATION	
Wood waste	Logging residue	Sorting	Briquetts	External Combustion	Pulver burner	Rankine	Steam Turbine
	Wood waste	Cleaning	Pellets		Fixed grate		ORC
	Bark	Chipping	Wood pulver		Inclined grate	Gas Turbine	IC/Rec
	Saw dust	Grinding	Black liquour		Underfeed		Combined C.
Energy Crops	Willow	Drying	Biogas		Travelling grate		Evaporative
		Compacting	Landfill gas		Vibration grate		Cheng/STIG
		Pressing	Product gas (gasific.)		Spreader-stoker		Chemical Rec.
		Gasification	Methanol		BFB	Hybrid	PFBC
Agro Biomass	Energy grass	Cracking	Ethanol		CFB		GT/Boiler/ST
	Wheat	Pyrolysis	Organic oils		Oil/gas burner	Kalina	
	Beetroot	Fermentation	Biodiesel / DME		Catalythic comb.	Stirling	
	Rape	Destillation	Pyrolysis oil	Internal Combustion		Otto	
	Sorghum	Anaerobic Digestion				Diesel	
	Sunflower	Skifting		Electro-chemical		Fuel Cell	PAFC
Argro Residues	Straw	Boiling					MCFC
		Reforming					SOFC
Organic waste		Esterfication					PMFC / PEM

Regarding to rice husk, gasification and combustion (external and internal) are the main methods for cogeneration of heat and power. Many projects raging from very small gasifiers (5-20 kW_e) to large (50 MW_e) direct combustion condensing power plants are in operation or scheduled to be built. Based on a literature review for many regions and countries in the world, Bergqvist and Wårdh stated that gasification and direct combustion are the two most commonly used, proven and commercially viable options for heat and power production from rice husk (Bergqvist & Wårdh, 2007). The next part will describe the two technologies in more details.

2.3.1. Gasification

Gasification is primarily a thermo-chemical conversion of organic materials at elevated temperature with partial oxidation. In gasification, the energy in biomass or any other organic matter is converted to combustible gases (mixture of CO, CH_4 and H_2), with char, water, and condensable as minor products. Initially, in the first step called pyrolysis, the organic matter is decomposed by heat into gaseous and liquid volatile materials and char (which is mainly a non-volatile material, containing high carbon content). In the second step, the hot char reacts with the gases (mainly CO_2 and H_2O), leading to product gases namely, CO, H_2 and CH_4. The producer gas leaves the reactor with pollutants and therefore, requires cleaning to satisfy requirements for engines. Mixed with air, the cleaned producer gas can be used in gas turbines (in large scale plants), gas engines, gasoline or diesel engines (Salam, et al., 2010).

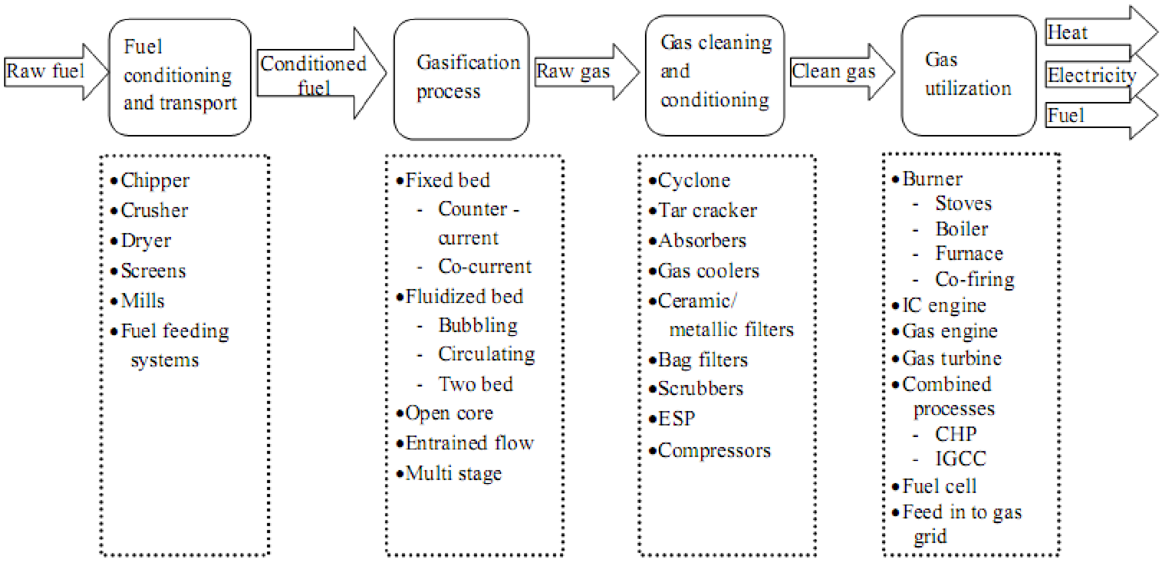


Figure 6: Basic process steps of a biomass gasification plant (Salam, et al., 2010)

Producer gas is a mixture of carbon monoxide, hydrogen and methane, together with carbon dioxide, nitrogen and other incombustible gases. The heating value of the producer gas, ranges between 4 to 20 MJ/m^3, depending on the carbon and hydrogen content of the biomass and the properties of the gasifier. This value also relies on the type of gasifier agent or the oxidant, which can be air, pure oxygen, steam or a mixture of these gases. Air-based gasifiers typically produce a producer gas containing a relatively high concentration of nitrogen with a low heating value between 4 and 6 MJ/m^3 (Salam, et al., 2010).

Gasifiers are usually available in small sizes, down to one or a few kW. For electricity generation, size of installed systems in China has been reported to be in the range of 200-1500 kW$_e$. Yet the units are modular which means they can be combined to form larger power plants (Bergqvist & Wårdh, 2007).

2.3.2. Direct combustion

External combustion offers the possibility to burn fuels in their natural form that is especially helpful in case of “bad fuels” which would destroy internal combustion equipment. Thus, these types of schemes are often referred to as direct combustion system, since no or little refinement of the fuel is made. The different types of technologies available for direct combustion represent 97% of global bio energy production and are promising for the nearest future. Direct combustion is also the most common way of producing heat and/or power from rice husk in both large and small scale applications (Bergqvist & Wårdh, 2007).

In the direct combustion system, biomass is burned to generate hot flue gases, which is either used directly to provide heat or fed into a boiler to generate steam. In the boiler system, the steam can be used for industrial purposes or space heating or even to drive turbines to generate electricity.

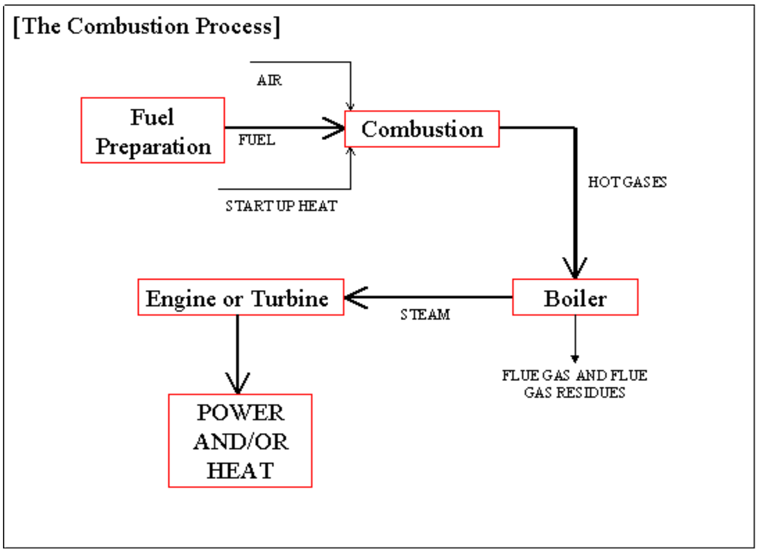


Figure 7: The combustion process (ESRU, 2002)

Direct combustion biomass facilities that produce electricity through a steam turbine have a conversion efficiency of 15% to 35%, depending upon the manufacturer; a CHP system can have an overall system efficiency of as much as 85%. The efficiency of a direct combustion biomass system is influenced by a number of factors including moisture content of the biomass, combustion air distribution and amounts, operating temperatures and pressures, fuel feed handling, distribution, and mixing, and furnace retention time (Kontor, 2013).

There are two main components of a combustion–based biomass plant: the biomass-fired boiler that produces steam and the steam turbine that generates electricity. The two most common forms of boilers are stoker and fluidised bed. Either of these can be fueled entirely by biomass fuel or cofired with a combination of biomass and coal. Typical boiler and steam turbine generating efficiencies imply about 10 MW electric output by 100 MMBtu/hr[2] heat input (EPA, 2007).

2.3.3. Choice of technology

When it comes to choose the most suitable technology for rice husk-based power plants, there are three main factors to be considered: available rice husk, ratio between heat and power demand, and fuel characteristics.

Despite the fact that gasifers can provide producer gas for combustion purposes, gasifiers are still preferred in small systems (below 1 MW thermal power) (FAO, 1986). Meanwhile, combustion will be used especially in large systems. Figure 8 and 9 below describe gasifiers range size based on electricity capacity and amount of biomass, respectively.

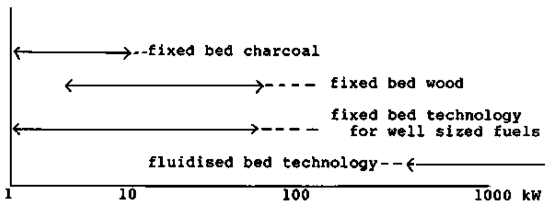


Figure 8: Gasifiers range size (FAO, 1986)

[2] 1 MMBTU = 1000000 BTU; 1 BTU = 1.054-1.060 kJ

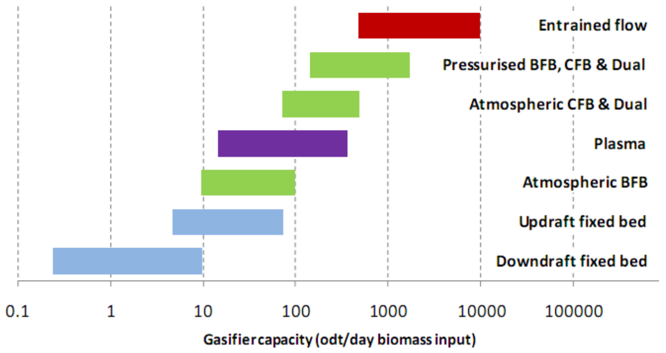


Figure 9: Gasifier technology capacity range based on odt (Oven Dry Ton) of biomass (E4Tech, 2009)

Regarding to combustion, Figure 10 indicates various equipments according to the desired capacity, raging from 2 kW to extremely large scale at 600 MW.

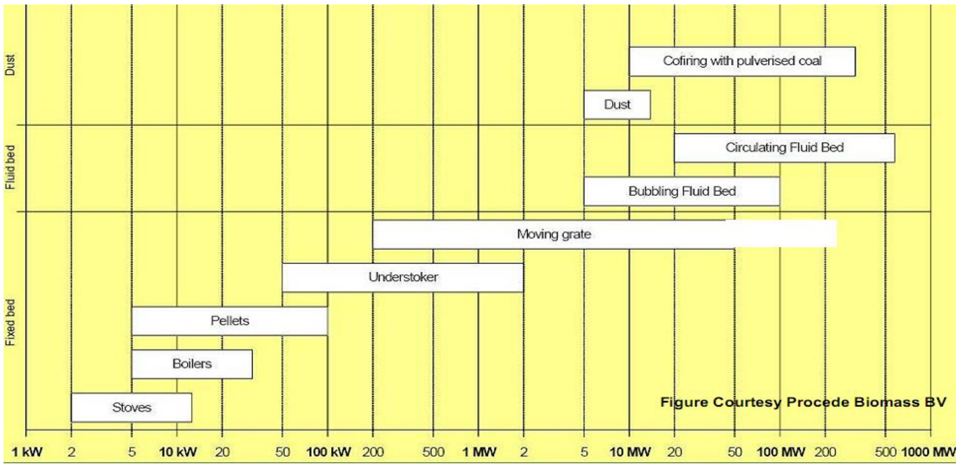


Figure 10: Combustion equipment range size (Preto, 2011)

Characteristics of fuel is another considertation. The pre-feastibility study conducted in 2004 on rice husk took moisture content, heating value, homogeneity, and ash content into account and suggested 3 schemes which satisfy the analysis on technology regarding to fuel characteristics (PREGA, 2004). They should be considered when making the choice of technical solution.

First scheme: Cleaned produced gas of biomass is preheated and led to gas turbine/I.C engine for combustion. Low investment cost and simple operation (few of facilities required) are the advantages of this scheme. However, it can be used for small scale power generation (up to 1000 kW) and it need tar removing process since along with operation, the dust/tar will accumulate on heat exchange surfaces.

Second scheme: Rice husk is gasified in a gasifier. Produced gas is led to gas turbine for combustion and power generation. The temperature of gas exhausted from gas turbine is still high enough to produce steam. This superheated steam will be led to the steam turbine to drive the generator producing electricity. This scheme has some advantages like high overall efficiency and high electric capacity.

Third scheme: Biomass is burnt in a furnace (fluidized bed/grate type) for preheating water and producing steam, which will be used in a steam turbine for driving the generator. This scheme has higher efficiency compared to the first one and easy to apply for cogeneration. It requires, therefore, higher investment cost and skilled operators.

The third factor, heat to power ratio (H:P), is defined as the ratio of thermal energy to electricity required by the energy consuming facility. It can be expressed as H:P = KW_{th}/KW_e, KW_{th} = the thermal load in KW and KW_e = the electrical load in KW (Mujeebua, et al., 2011). The conventional data for H:P and the expected overall efficiency of various cogeneration schemes are provided in Table 4.

Table 4: Heat-to-power ratio for various cogeneration options (Mujeebua, et al., 2011)

Cogeneration system	Heat-to-power ratio	Overall efficiency, %
Back-pressure steam turbine	4.0 - 14.3	84 - 92
Extraction-condensing steam turbine	2.0 - 10.0	60 - 80
Gas turbine	1.3 - 2.0	70 - 85
Combined cycle	1.0 - 1.7	69 - 83
Reciprocating engine	1.1 - 2.5	75 - 85

Besides, Jimerez O. L. has reported that gas turbine is suitable for process sites having H:P ratio ranging 2.0-4.5 (maximum), while steam turbine should be applied for the ones having H:P ratio at 4.5 upwards (maximum) (Jimenez, 2010). Some typical features of several co-generation equipments can be seen in table 5.

Table 5: Typical parameters of several CHP systems (Jimenez, 2010)

Type of plant	Typical output range	Typical fuels	Typical H:P ratio	Grade of heat output
Gas turbine	0.5 MW_e upwards (over 200 MW_e)	Natural gas, gas oil, landfill, biogas	1.5:1 to 3:1	High (usually used in HRSG)
Compression engines	2 MW_e upwards (till 15 MW_e)	Natural gas + 5% gas oil, heavy fuel oil	1:1 to 1.5:1	Low
Spark engines	Up to 4 MW_e	Natural gas, landfill, biogas	1:1 to 1.7:1	Low
Steam turbine	0.5 MW_e upwards	Any ut converted to steam	3.1:1 to 10:1	Medium
Combined cycle	3.5 MW_e	As gas turbine	Down to 1:1	Medium

Figure 11 below shows the total amount of installed capacity according to different CHP movers in the United States. While combined cycle is more suitable to district heating, gas and steam turbines are the best types of CHP for industrial processes because of their large capacity and ability to produce the temperature of steam most needed by these processes. Reciprocating internal combustion engines (ICEs), on the other hand, are widely used in small-to-medium applications (under 10 MW), so are well-suited for commercial as well as light-industrial situations. (Environmental Leader, 2013).

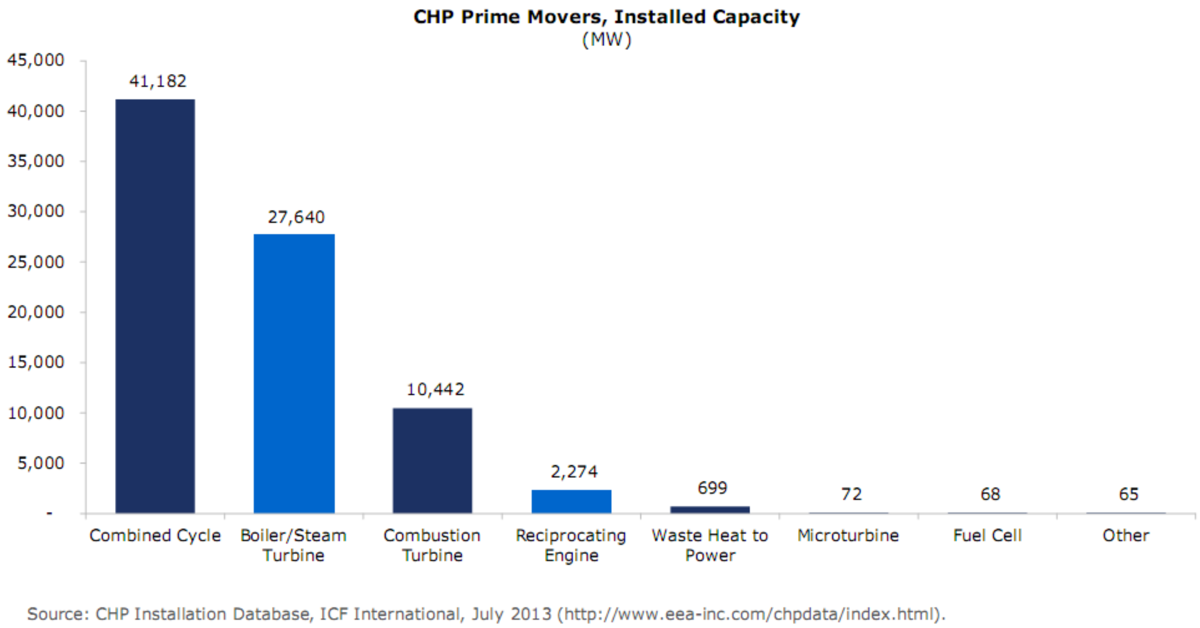


Figure 11: Installed capacity of various CHP Prime Movers in the US (Environmental Leader, 2013)

2.4. Identification of problems for rice husk-based power plants

There are a large number of rice husk-based power plants which were built and operated in the world, especially in the East Asia. However, many of power plants using gasification method have been failed due to a vast array of reasons, both technical and non-technical problems. For example, in Thailand, almost all the gasification plants for electricity generation application have failed after a short period of operation, with the causes relating to high tar content, the fuel properties and gas, and more importantly, inadequate resource supply or the high prices for as rice husk, lack of trained operators for imported plants (Salam, et al., 2010).

In Cambodia, about 55 biomass gasification plants were identified, of which almost all are for electricity generation applications for rural electrification and small and medium enterprises. Technology for most of the plants is from Ankhur Technologies- India and most of the plants are 200 kW in capacity with the maximum installed capacity of 600 kW_e (2x300kW_e, under construction). Almost all the gasifiers use producer gas and diesel in a dual fuel mode, replacing about 75% of the diesel usage. The major non-technical barrier is the lack of availability of technical expertise and training and awareness programs for plant operators (Salam, et al., 2010). Therefore, there are both technical and non-technical barriers which need to be identify in order to for new plants of the same kind can be successul in power generation.

2.5. Vietnam and the rice industry

2.5.1. Introduction of Vietnam

Vietnam, officially the Socialist Republic of Vietnam, is a developing country locating on the easternmost land of the Indochina Pennisula in Southeast Asia, covering an area of 331 thousand km^2. It is bounded by Cambodia, Laos, China, and the South East Sea. With its population standing at 88.7 millions inhabitants in 2012 (GSO, 2013) and according to later estimations in 2013 and 2014, it is the world's 14th-most-populous country (CantyMedia, 2014). The country has a high population density, 268 person/km^2 in particular.

Approximately half of total employed population, namely 25 million (WB, 2013), works in the sector of agriculture, forestry and fishing. Although holding the lion share of workers, this sector is only accounted for nearly 20% of GDP, in comparison with services (42%), and industry and construction (38%). Among all argricultural products, paddy is grown in roughly 12% of land in total, equals to 40% of all production land for agriculture (GSO, 2013).

Seventy percent of the population lives in rural areas, mainly in the two rice-growing deltas: the Red River Delta in the north and the Mekong River Delta in the south. The country's primary production is rice, coffee, rubber, cotton, tea, pepper, soybeans, cashews, sugarcane, peanuts, bananas, fish, seafood, and poultry (GRiSP, 2013).

The year 1986 marked the point of time when the Reform in Vietnamese economy started. Vietnam has changed from a highly centralized planned economy to a socialist-oriented market economy that uses both directive and suggestive planning. With the country's commitment to economic liberalization and international integration, it employed structural reforms required to modernize the economy and to create more competitive export-driven industries. Vietnam joined the World Trade Organization in January 2007, which secured the country's link to the global market and fortified the domestic economic reform process. Moreover, Vietnam becamse an official partner in developing the Trans-Pacific Partnership trade agreement in 2010. This agreement brings together a significant number of Asia Pacific Economic Cooperation (APEC) economies under a single free trade agreement (GRiSP, 2013).

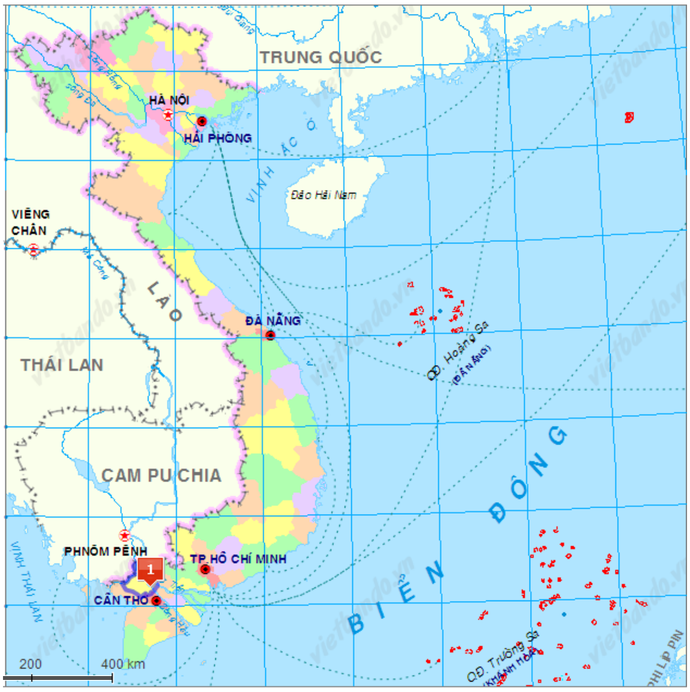


Figure 12: Vietnam on map (Vietnam, 2014)

2.5.2. Rice industry

Vietnam is the world's fifth-largest rice-producing country. Rice production has continuously increased, from 25 million tonnes in 1995 to almost 40 million tonnes in 2010. This increase can be attributed to some expansion of rice harvested area and higher yield. Rice yield improved to 5.3 tonne/ha in 2010 from 3.7 tonne/ha in 1995. The use of input-responsive modern varieties, sufficient fertilizer, and an increase in the proportion of rice area (93.4%)

under irrigation account for the high yields in recent years. Although the rice area harvested expanded from 6.8 million hectares in 1995 to 7.5 million hectares in 2010, annual growth was only 0.5% from 2005 to 2010 (GRiSP, 2013). The average yield surged from 4.24 tonne/ha in 2000 to 5.32 tonne/ha in 2010. The number rose to 5.63 tonne/ha in 2012 (Vietrade, 2013).

Surprisingly, before 1986, the country had to import rice, because rice production could not meet domestic demand. Present rice policies in Vietnam are a balance between maintaining domestic food security and promoting rice exports. Government intervention is limited in the domestic market and a majority of rice exports in the country are made through state-owned trading enterprises (50% share), particularly by the Vietnam Food Association (VFA). VFA buys rice from farmers to keep the price of rice stable and also to prevent rice importers from haggling for prices too low during the harvest season (GRiSP, 2013).

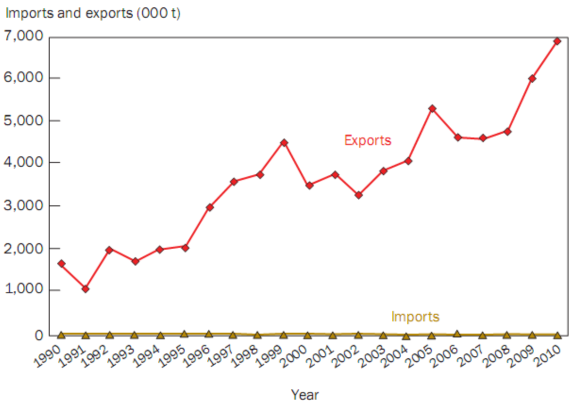


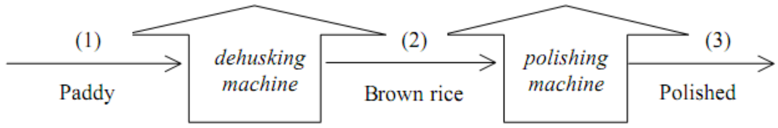
Figure 13: Vietnam's rice import and export (GRiSP, 2013)

For many years now, rice production plays the most important role in Vietnam's food security and rural economy which generates jobs for a large amount of the country's labor force and is a source of export revenue. The two main granaries in Vietnam are Red River Delta in the North and Mekong River Delta in the South with the sown areas of 1.144 million hectares and 4.089 million hectares, respectively (Vietrade, 2013).

Vietnam is one of the world's leading rice exporters with it holding the second rank for several years. The country's rice exports reached 5.3 million tonnes in 2005 and almost 6.9 million tonnes in 2010 (GRiSP, 2013). The year 2012 saw the production amount setting at 43.7 million tonnes of paddy. Of which 8 million tonnes of rice was exported to the world's market (GSO, 2013).

2.5.3. Rice milling sector

The Reform has brought about opportunities for Vietnam's rice to be exported. Given the then existing rice milling technology that was only able to produce rice for domestic consumption, the milled rice did not meet export standards. At that time, private rice millers in Vietnam, especially those in the MRD who produce most of export rice of the country, were under pressure of improving the quality of their output. Those rice millers that already had rice milling factories established might found it wasteful to demolish the existing factories to build up new ones. They thus tend to set up polishers separately to only polish rice to export. In case the rice mills were at start-up phase, they might have insufficient capital to set up factories that can perform both milling and polishing functions. They thus opt for either milling or polishing function (Le, 2003). These reasons can be used to explain the existence of the so-called "two-system" milling process in the MRD, which is described in Figure 14.



Note: (1) Paddy is fed into dehusking machines in order to get brown rice; (2) brown rice is taken out of dehusking machines and is then fed again into polishing machines to get polished rice; and (3) polished rice comes out of polishing machines.

Figure 14: The two-system milling process in the MRD (Le, 2003)

There are more than 100000 rice mills distributed all over Vietnam. Of these, about 99% are small scale with milling capacities of less than 100 tonnes/shift or 30 tonnes/day, on paddy basis (Bergqvist & Wårdh, 2007). Besides, almost all this kind of mills in the Mekong Delta is small- or medium-scale enterprises (Dang, et al., 2010). However, in the light of the Decree No.109/2010/ND-CP of November 4, 2010 on rice export business which requires rice export enterprises must have at least one rice mill with an hourly capacity of at least 10 tonnes of paddy and possess at least one warehouse which can store from 5000 tonnes of paddy (Vietnam, 2010), a promotion for bigger scale rice mills has been appearing in Vietnam.

2.5.4. Environmental issues of rice husk

In Vietnam, it has been reported that the high volume of rice husk that is considered as waste after milling are not appropriately treated. Part of them is dumped into the dense canal and river systems, polluting the waters and disturbing the habitat for fish populations. By covering the water surfaces, the disposed rice husk decreases the dissolved oxygen significantly, and further causing pungent odors, black color and high turbidity in the aquatic environment. These problems, as a result, generate economic costs by increasing the fees for managing catfish disease and reducing productivity. Furthermore, communities living along the rivers are also affected due to their using of polluted water for bathing, washing and drinking (Pham, et al., 2011).

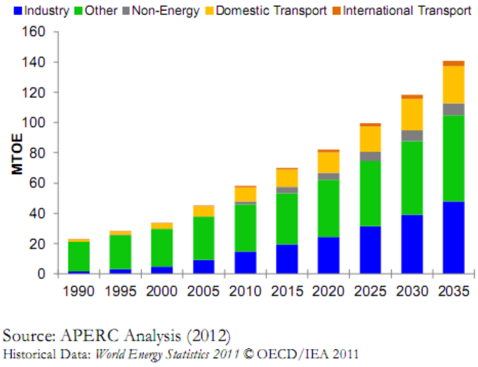
According to (Pham, et al., 2011), Rice husk dumping into the rivers is still observed today, especially in rural areas, even though the practice is illegal and has been strictly banned in Vietnam. If it is not disposed into water environment, as an alternative rice mill owners often burn the excess husks in the open air which is becoming increasingly prevalent. This kind of treatment causes not only respiratory disease but also severe fire accidents, and many countries have introduced new regulations to restrict field burning of rice husks.

2.5.5. Energy sector

2.5.5.1. Energy

Vietnam possesses diverse fossil energy resources, including oil, gas, and coal, as well as renewable energy resources such as hydro, biomass, solar, and geothermal. Coal reserves are found in the northern part of the country, while natural gas and crude oil are mainly placed offshore in the south (APEC, 2013).

Given APEC's business-as-usual (BAU) assumptions under the current economic conditions, total final energy demand for Vietnam will continue to rise at an average annual rate of about 3.6% over the outlook period. As a result, in 2035 the total final energy demand will reach about 140 Mtoe, which is a more than two-fold increase on 2010 levels. Energy consumption is projected to increase in every sector of the economy, due to the growing modernization within the nation.



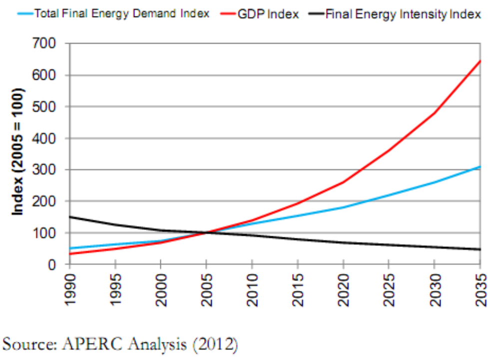


Figure 15: Vietnam's BAU final energy demand (left); Figure 16: Vietnam's BAU final energy intensity (right) (APEC, 2013)

By the end of the outlook period in 2035, oil is expected to hold the largest share of the final energy demand, namely 34%, followed by electricity (24%) and coal (22%). During 20 years (from 2010 to 2035), the consumption of gas is projected to grow the fastest, at an average rate of 7% per annum. Final energy intensity is expected to decline by about 52% between the period of 2005 – 2035 (APEC, 2013).

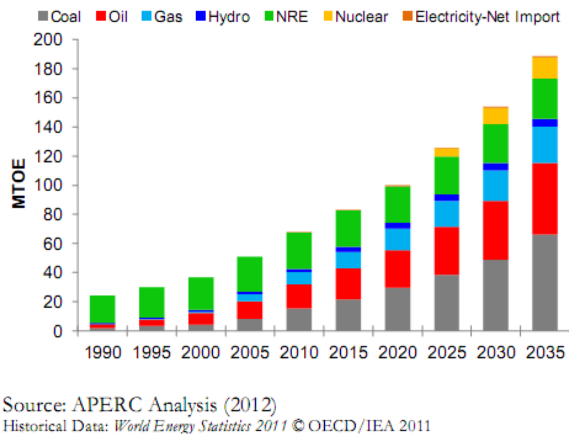
The report from APEC also indicates that Vietnam's primary energy supply is projected to increase almost three-fold over the outlook period, from 68 Mtoe in 2010 to about 188 Mtoe in 2035, due to an average annual increase of 4.2%. The proportion of non-commercial energy sources, firewood for example, in the mix will decrease gradually. These kinds of source made up 37% of the primary energy supply in 2010, yet in 2035 they will provide just over 15%, because rising household incomes and the shift to urban centers prompts a shift to commercial energy sources.

2.5.5.2. Electricity

The rapid expansion of Viet Nam's economy between from 1995 implied electricity demand increased dramatically in the same period. The average rate of growth per year during 15 years, from 1995 and 2009, was 13%. To be spesific, the 2009 electricity demand, namely 83.2 TWh, was grown to 14.4 TWh in 1995, nearly six times greater. Peak demand increased more than four times during this period, rising to 13.8 GW compared to 3.2 GW in 1995. The potential peak demand was even higher than reported, as power shortages led to load shedding and cuts in electricity supply during peak hours (APEC, 2013).

In 2012, power generation in Viet Nam was based on these sources: gas (28.8%), hydro (47.5%), coal (17.8%), oil (2%), import (3.5%) and other (0.2%) (EVN, 2013). The construction of new electricity plants using nuclear, hydro, and renewable energy sources has met a number of difficulties, such as the availability of resources, construction sites, and high production costs.

Some development of hydro and nuclear power plants will still be carried out to meet the demand growth and therefore, this will contribute to the projected five-fold increase of electricity supply by 2035.



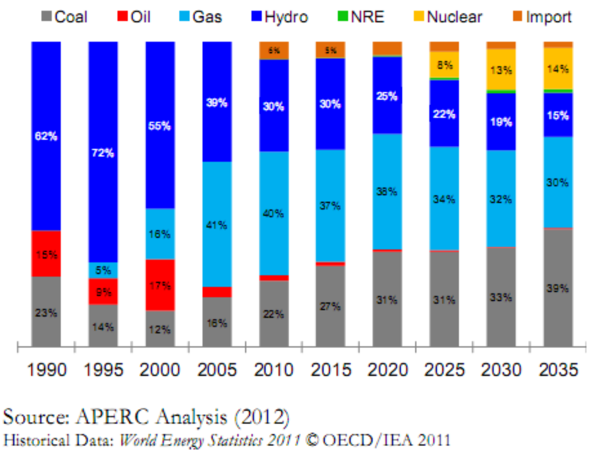
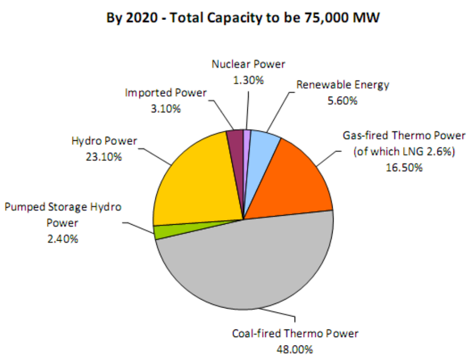


Figure 17: BAU primary energy supply (left)**;** Figure 18: BAU electricity generation mix (right) (APEC, 2013)

As can be seen on the graphs (Figure 17 and 18), electricity generation is projected to increase at an average annual rate of 6.1%, reaching 409 TWh in 2035. Because the government continues to pursue its goal of increasing the use of domestic resources, new renewable energy sources (NRE) are expected to contribute to electricity production, especially in remote areas where connection with the grid may be not reliable. Therefore, NRE's share will increase from zero in 2009 to the 2035 figure of 1%.



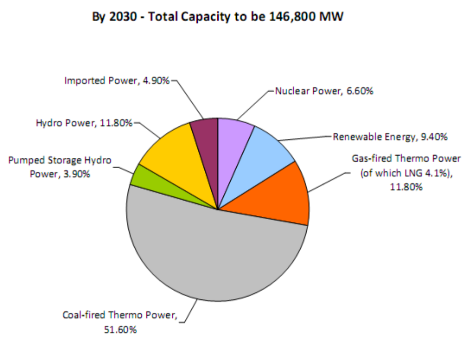


Figure 19: Capacity contributions by 2020 (left); Figure 20: Capacity contributions by 2030 (right) (APEC, 2013)

In Vietnam, the government-owned electricity corporation (Viet Nam Electric Power Group – EVN) takes charge of the national electrical grid. For example, in 2009, total installed electricity capacity in Vietnam was 18481 MW; 69% out of that total was managed by (EVN), while 29% was managed by others. In addition, more than 4.1 TWh was imported from China (Kovac, 2012).

At the end of June 2005, the national power grid has reached all provinces, connecting 95% of communes and 89% of households in rural areas. By inter-connecting several regional grids, EVN plans to develop a national electricity grid at the end of 2020. A North-South power cable transmits electricity from Vietnam's largest generator, the Hoa Binh hydropower plant in the North, to large population centers in the South, contributes to electricity shortages in Ho Chi Minh City. The total distribution network of EVN extends 19396 km. Transmission takes place at 500 kV, 220 kV and 110 kV, with a distribution network of 35/22 kV medium-voltage (Kovac, 2012).

2.5.5.3. Biomass-based energy generation

According to a report on renewable energy in Vietnam, biomass resources that could be used for generating electricity include rice husk, paddy straw, bagasse (sugar cane, coffee husk, and coconut shell), wood and plant residue, with an annual output of approximately 93 million tonnes, and an estimated potential of 1000-1600 MW. Total amount of argicutural residues for energy usage is estimated at roughly 75 million tonnes (Table 6). In addition, it is estimated that 25000 household biogas digesters have been installed in the country since the 1960s. The livestock population is approximately 30 million, although the lack of industrial-scale poultry or pig farming makes large-scale biogas production difficult (RECIPES, 2006).

Rice husking plants in the Mekong Delta region could fuel a power station with a capacity of 70 MW, and waste materials from sugar cane could produce 250 MW. In 2005, the first 750 kW waste-to-power project was completed (with 16 million USD of investment). Two additional turbines were commissioned in 2006, with the potential to generate about 250-400 MW in total (Kovac, 2012). The Power Development Master Plan of Vietnam considers biomass as a energy resource, with its projected installed capacity increasing in the future, landing at roughly 2000 MW in 2030, as can be seen in Figure 21.

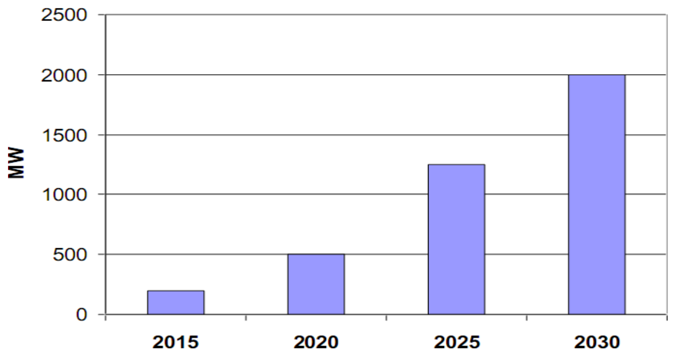


Figure 21: Plan for biomass-based electricity generation in Vietnam (total capacity) (Vietnam, 2011)

According to (Nguyen, 2013), by 2013, there have been 40 bagasse cogeneration systems installed in 40 sugar mills with capacity ranging from 1 to 25 MW_e, totalling 150 MW_e. Among those, five cogen systems have been selling extra electricity to national grid at average price of 4 UScent/kWh, and 15-20 plants have plan to expand their power capacity by installing new boiler, turbine and generator.

Table 6: Amount for energy usage of several agricultural residues in Vietnam (Nguyen, 2013)

Biomass resource	Amount for energy usage (million tonne)
Rice straw	40.0
Sugar wastes (tops and leaves)	7.80
Corn residues	9.20
Cassava sterms	2.49
Rice husk	8.00
Bagasse	7.80
Groundnut shells	0.15
Coffee husk	0.17
Cashew nut shells	0.09
Others (estimated)	4.00
Total	74.90

One rice husk fired power plant existed with installed boiler and selling steam in industrial zone at price of 25-30 USD/tonne (at 7 bar, as saturated steam). Besides, 10 rice husk fired power projects have been reported to be under documents. In addition, more than 30 wood processing plants installed wood chip fired fixed grade boilers for drying products (Nguyen, 2013).

Table 7: Characteristics of several biomass fuels (Nguyen, 2013)

Characteristics of main biomass fuels	Rice husk	Bagasse	Rice straw	Wood/wood wastes
Density (kg/m^3)	120	260	400	500
Heating value (kcal/kg)	3000	1850	2800	3500
Average moisture content (%)	14	50	29	25
Ash content (%)	16 – 18	2 – 5	10 – 15	1 – 3

2.5.6. Energy policy

Main energy policy publications in Vietnam which are still in force include the National Energy Development Strategy for the period up to 2020, with an outlook to 2050; the Renewable Energy Action plan; and the Power Development Master Plan of Vietnam period of 2011-2020, outlook to 2030 (Kovac, 2012). They identify biomass as one of the energy resources for the future development of the country.

Recently, the Decision No. 24/ 2014/QD-TTg of March 24, 2014 on the support mechanism for the development of biomass power projects in Vietnam has been issued. In term of electricity price to be sell to the grid, for combined heat and power projects, the purchaser (most likely EVN) is obligated to purchase entire redundant electricity generated from combined heat and power projects using biomass energy at the delivery point at 1220 VND/kWh (excluding VAT, equivalent to 5.8 US cents/kWh). The electricity purchase price shall be adjusted to the fluctuations in VND/USD exchange rate (Vietnam, 2014). This policy is expected to support the existing bimass-based power projects, and promote the development of new ones.

2.5.7. Potential of rice husk for thermal power plants in Vietnam

The production of rice husk in Vietnam were maintained approximately 8 million tonne/year (Table 6), accounted for more than 10% of all argo-residues. However, this number is not evenly distributed according to local, regional and seasonal. It depends on locations and seasons during the year (Quyen, et al., 2012).

The noticeable amount of rice husk produced in Vietnam has a high potential to be utilized as energy resource. Utilization of the co-generation system to meet the requirement of thermal and electrical needs specially for generating steam and or hot air for parboiling and drying of paddy will help in enhancing the energy efficiency and production capacity of rice mills (Pandey, 2007). Considerable savings can be obtained via thus kind of use, besides it leads to an increase in production capacity, a sustainable supply of electricity and additional revenue form the surplus electricity generated from saved rice husk.

According to the survey of the Mekong Delta Development Institute for 108 rice mills, which were randomly chosen, at 14 districts in Can Tho City, An Giang, Kien Giang, Hau Giang and Soc Trang, about 20% of rice-husk at factory was sold for household purposes or fertilizer with price range from 40 to 170 VND/kg, or 1.9 to 8.1 UScent per kg, depending on locality and time of year. These results also show that the rice-husk reserve at the factory is 232 thousand tonne/year. The reserve of unused rice-husk is about 1.5 million tonne/year which can be used for electricity generation purposes to provide an amount of 1 to 1.2 TWh yearly (Quyen, et al., 2012).

The first rice husk-fired power plant was reported to be built in Tan Phuoc district, Tien Giang which has 10 MW of installation capacity. Another power project with 7MW of installation capacity was developed by Dinh Hai Thermal Power Company (DHTPC) at Tra Noc Industral Zone (Can Tho City), this company also planned to construct another plant with 10 MW of installation capacity which was supposed to locate at Thot Not IZ (Can Tho). It was also reported that Duy Phat Power Company planned to develop a 10-MW cogeneration system at Binh Hiep B, Lap Vo district, Dong Thap province (Quyen, et al., 2012).

Recently, there has been information of a project to build 20 thermal power plants fueled by rice husk in Vietnam. The first one was expected to begin in late December 2013 in Hau Giang province with a total investment of approximately 31 million USD. According to the project, the plant has 10 MW capacity and will consume 250 tonne of husk each day. Waste from the plant will be utilized for cement production and insulation materials. The other power plants of the same kind are planned to erect in many locations in Vietnam, the Mekong Delta in particular will have 5 plants locating in the provinces of An Giang, Kien Giang, Hau Giang, Dong Thap, and Can Tho with a total capacity of 200 MW (Vietnamnet, 2013).

2.6. An Giang Province

2.6.1. Location and features

An Giang province locates to the west of the Mekong Delta between the Tien and Hau rivers and shares a 100 km border with Cambodia in the north–west, as depicted in Figure 22. Additionally sharing border with Dong Thap province in the east, Can Tho City in the south east, and Kien Giang province in the south-west, it lies next to the Cuu Long River (the part of Mekong River in Vietnam) and consists of a few midland areas and low mountains. The weather in An Giang is divided into two seasons: the rain (between May and November), and the dry that occurs between December and April next year (Vietnamtourism, 2011).

Thanks to the flood season, the alluvium of the Mekong River enriches the soil, making it fertile and suitable for growing wet rice; there are about 300 thousand ha for growing two crops of rice with a productivity of over 3 million tonnes per year, and 600 thousand ha of low aluminium soil in the Long Xuyen Belt being improved. The growing of tropical fruit trees, husbandry (e.g., buffaloes, cows, pigs, poultry), pisciculture and apiculture are developed (Vietnamnow, 2012).

An Giang has 2.15 millon habitants with a density of 609 person/km^2, higher than the country’s average (GSO, 2013). The province has one city (Long Xuyen), one provincial town (Chau Doc) and 9 districts (Chau Phu, Chau Thanh, Cho Moi, Phu Tan, Tinh Bien, Tri Ton, Tan Chau, Thoai Son and An Phu), all of them are covered within the geographical boundary of this research.

Figure 22: Mekong Delta River with its waterway system (LesAteliers, 2008) and An Giang’s location (Pham, et al., 2011)

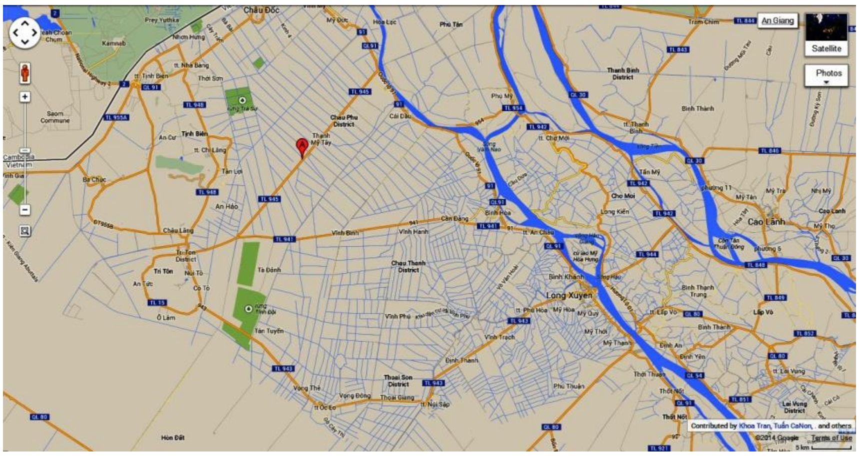


Figure 23: An Giang’s canal system (GoogleMap, 2014)

In An Giang, waterways and roadways strongly link to one another. Although 70% of total goods are transported on roads, they are responsible for only 20% of goods in mass (LesAteliers, 2008). There are 280 rivers and canals distributed at a density of 0.72 km/km^2, the highest river density in Mekong River Delta provinces, which can adequately supply water for productive and domestic activities in plain areas of the province. However, the dominion of hydrological systems in An Giang heavily depends on the level of water in Mekong River. During 2.5-4 months every year, 70% of land area in the province is flooded less than 1-2.5 meters of water. This is a serious problem affecting socio-economic development of the province (PREGA, 2004).

Figure 23 describes how An Giang is criss-crossed by many rivers and canals which make a convenient water transport system. On this map, the network of blue lines indicates the matrix of canals and rivers. The two tributaries of the Mekong river, the Tien and the Hau, run across the province. As a result of their delivering a great deal of alluvium annually to the land, several islets have been formed which are extremely fertile and covered with lush green vegetation.

2.6.2. Energy sector in An Giang

In term of the power supply system, An Giang administrates about 100 km medium voltage one phase line, 200 km medium voltage 3 phase line, nearly 2000 km low voltage line and about 2000 substation with the total capacity of 100 thousand KVA. The electricity consumption is reported to be more than 1.2 billion KWh/year used by 250 units (InvestinVietnam, 2011).

Being one of the most productive locations for agricultural products, especially paddy grain, potential of biomass-based energy generation in An Giang should not be ignored. Utilization of these renewable energy sources have been paid a great deal of attention by the provincial government, proven by the cooperation project between An Giang province and Swedish stakeholders to support initial project development in the area of energy efficiency and renewable energy. The An Giang People´s Committee and the Swedish Energy Agency (SEA) have been implementing a partner driven cooperation programme since 2012 with the overall objective aiming to provide capacity building to the public and private sector in order to facilitate and increase the realisation of bankable energy efficiency and renewable energy projects in the province. The project is still on-going at the moment, with its plans for the near future (Piteå kommun, 2011; Kjellström, 2013).

2.6.3. Need for rice husk-based power systems

Being one the most important locations for rice production in Vietnam, 73% of An Giang's total area, which is 258 thousand hectares, are paddy land. During the year, the total amount of planted area of rice is 625 thousand hectares, one of the largests in Vietnam. Its rice production has been ranked 2 at national level for several years, with the amount being 3.94 million tonnes and yield of paddy is 6305 quintal/ha (Department of Statistics, 2012). Rice husk production is therefore about 0.78 million tonnes per annum. Based on current data, these amounts are expected to increase gradually.

In the province, there are more than 1000 rice mills, of which more than 200 have larger capacities above 100 tonne/day. Most rice mills are located on the banks of canals and the two major rivers, taking advantage of the dense water transport network. It was reported that this province suffers from serious pollution problems from inadequate rice husk waste disposal (Pham, et al., 2011).

According to the reasearch conducted by Pham T.M.T. in An Giang in 2010, uses for rice husks included cooking and brick kiln (Pham, et al., 2011). However, on a recent report from the collaboration project (see section 2.6.2.), rice husk briquetting has been becoming more and more significant for the past years (Kjellström, 2013). The uses of rice husk heavily depend on profits they can bring to the owners. Since cost of electricity consumption for briquetting is projected to grow in the future, along with the electricity price, utilization of this biowaste for power generation likely become attractive to local rice mills, especially with co-generation systems where they are able to extract heat for drying. This kind of cogen systems are therefore asking for more attention, in particular at rice-mill level. It is also one of the business plans that is developed within the mentioned collaboraton project focusing on co-generation of heat and power plants fueled by rice husk at small and micro scale.

2.7. The Clean Development Mechanism

The Clean Development Mechanism is known as one of the key components of the Kyoto Protocol. As an offshoot of the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol is a legally binding global agreement to combat climate change through a reduction of greenhouse gas (GHG) emissions (came into force on 16 February 2005) (Shrestha, et al., 2005). The Protocol follows the fundamental UNFCCC principle of "common but differentiated responsibility" which recognizes that the burden of responsibility should fall heaviest on the countries which have historically emitted the greatest quantity of GHGs. The Protocol legally requires the highly industrialized and developed countries (categoried as Annex 1 Parties) to achieve quantified reductions in human-made GHG emissions. The less developed countries (non-Annex 1 Parties), that are the smallest emitters, yet the most vulnerable to climate risks, have no binding reduction targets (Marciano, 2008).

The stated purpose of the Clean Development Mechanism is to help developing (non-Annex 1) countries achieve sustainable development, and assist industrialized (Annex 1) countries in complying with their emission reduction commitments. Its scheme is as simple as that private companies fund projects in developing countries that reduce greenhouse gas emissions. It is also a must for the companies to meet sustainable development criteria and the “additionality” requirement, which means the emission reductions made must be “additional” to what would have been possible without CDM funding. The CDM awards these projects certified emission reductions (CERs), each accounted for one tonne of carbon dioxide, upon some verification. CERs are then sold to developed countries, these nations use them to meet a part of their reduction commitments under the Kyoto Protocol. This is why CERs are also called “offset credits” because they “offset” the developed countries’ emissions with reductions in developing countries (Marciano, 2008).

Roughly 7500 CDM projects have qualified for carbon credits. Most of these are large-scale activities conducted in the energy sector and the waste sector, i.e., subsidized technologies include landfill gas, incineration, and cement kilns. As can be found on the CDM's website[3], 34 rice husk-based power or cogeneration projects have been registered so far. With a combined share of more than 70% of the projects, India and China are the biggest beholders. Vietnam is the host party for about 3.4% of all registered projects. Besides, approximately

[3] http://cdm.unfccc.int/

1170 further projects are undergoing validation, a step prior to submission to the Board for registration (UNFCCC, 2013).

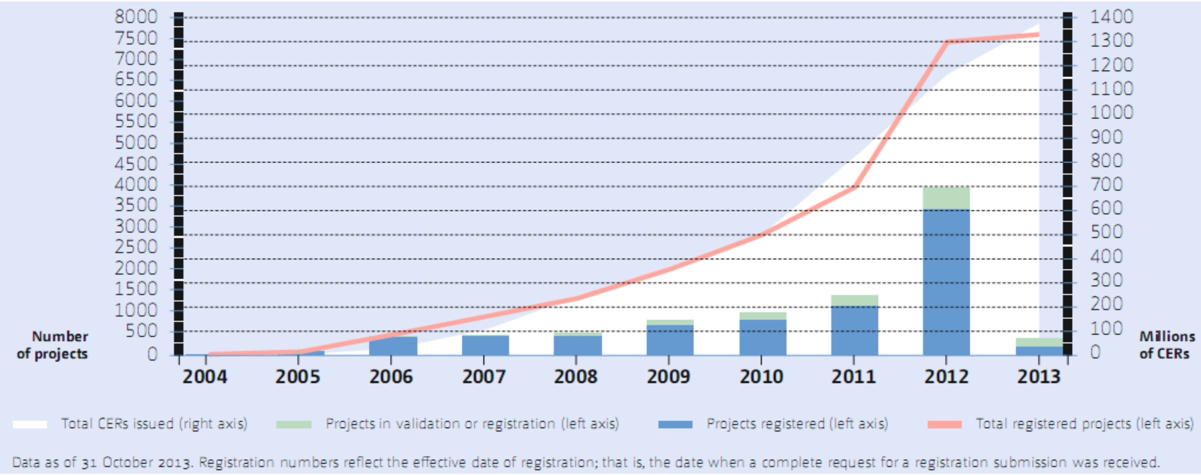


Figure 24: Certified emission reductions issued cumulative, projects registered cumulative, and projects registered, registering and in validation by year, 2004–2013 (UNFCCC, 2013)

By the end of 2013, the CDM has been produced roughly 1.3 billion CERs (Figure 24). However, as the graph below (Figure 25) illustrates carbon price according to different system, price for EUA and CER has been declining significantly, especially for CER. Spot prices for EUAs declined from an average of around €13 ($A20.30) in January 2010 to around €3.90 ($A4.90) by the end of April 2013 (Talberg & Swoboda, 2013). Prices for emissions units, which are derived in the market, are subject to a range of demand and supply factors.

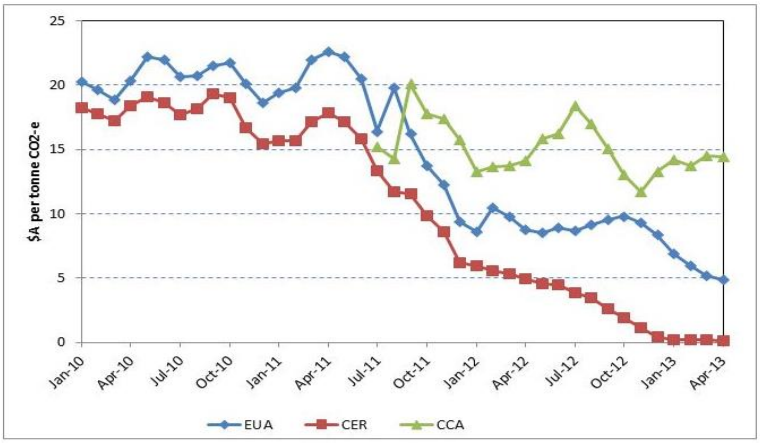


Figure 25: Carbon prices for EU ETS and California ETS, selected permit types, January 2010 to April 2013 ($A) (Talberg & Swoboda, 2013)

Note: Prices are spot prices as compiled by Point Carbon based on exchange-traded and OTC transactions. EUA = European Union Allowance, CER = Certified Emissions Reduction, AU = Australian Unit, CCA = California Carbon Allowance.

Another concern is that while the rich countries have been purchased carbon credits and enjoying vicarious emission reductions as a way to meet their Kyoto obligations, the CDM has yet to be shown that it is indeed helping poorer countries move forward to a more sustainable future (International Rivers, 2008).

2.8. Define research questions

As mentioned earlier, the economic development of the An Giang province has been creating an increasing energy demand. This province possesses not only a large number of rice mills at different scale that produce an abundant amount of rice husk yearly, but also an extremely convenient waterway systems which is indeed an advantage for rice husk utilization. Although at the moment there are several uses for this agricultural residue, difficulties can appeare in the future, e.g., when electricity cost for rice husk briquetting is higher than the briquettes' market value. Therefore, it is worth thinking about utilizing this resource for power and heat co-generation. Moreover, the large number of rice mills in the region and profit-related issues make it necessary and interesting to evaluate the situation where rice mills possess their own power plants which directly consume the husk produced.

Although there are several assessments of potential of utilizing rice husk for energy production in Vietnam, especially in the Mekong River Delta, only a few of them targets particularly to An Giang. Despite of one existing pre-feasibility analysis of a 500-kWh-rice-husk-based power plant at a rice mill which was supposed to consume 5 tonnes of paddy per hour in the same province eleven years ago (PREGA, 2004), it is out of date now to be consider for new possible power plants. The report focused on three perspectives, namely technical, economic, and CO_2 reduction, yet did not take CER credits into account. It also did not include consideration for briquettes made from rice husk, whose market has been active for the past 6 years in the region. Futhermore, another aspect could be thought of is how many job vacancies can be created for local and non-local individuals by constructing new power plants.

On the other hand, a research on greenhouse gas emission mitigation potential of rice husks conducted for An Giang province (Pham, et al., 2011) has provided information on the uses and amounts of this agricutural residue, yet lacks other features such as logistics, market and price, in order to see the whole picture of current status. While the analysis focused on GHG emission of different technologies, i.e., combustion and gasification, for two types of power capacity (5MW and 30MW), other aspects of feasibility study were not included.

In addtion, although both mentioned reports considered some concerns for pocily, the recent Decision of March 24, 2014 on the support mechanism for the development of biomass power projects in Vietnam (Vietnam, 2014) has not appeared in any available assessments.

It is known that there have been a few power plants fueled by rice husk built and operated in Vietnam. However, they are believed to be unsuccessful in term of electricity generation. Investigation on the causes is necessary in order to succeed with the new possible power plants. This information has been provided in documents.

Thus, this research has three aims. Firstly, it provides an overall picture of rice husk-related issues (logistics, market and price, current uses, etc.) in An Giang. Secondly, an investigation of the reasons why rice husk-based power plant(s) built in other locations failed to generate electricity is carried out. The third point is to produce a pre-feasibility assessment concerning technical and economic solutions, as well as environmental and social aspects, of two possible power plants owned by two chosen rice mills which are likely to be constructed in the future.

3. Methodology

3.1. Framework

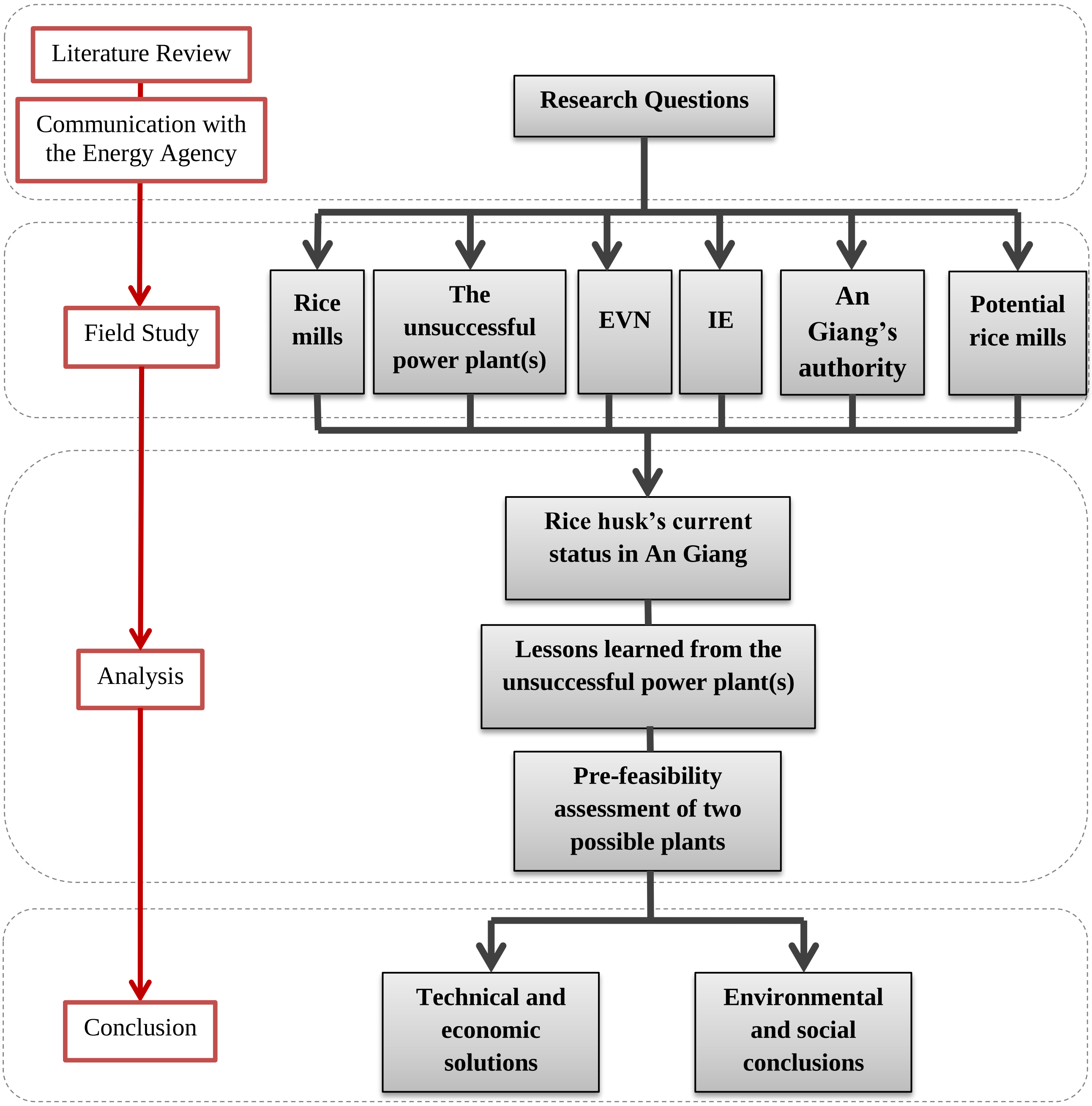


Figure 26: Framework of the methodology

In order to collect real-life data for the analyses, a field trip was conducted in several locations Vietnam for a duration of 7 weeks (27th of January to 16th of March 2014). The field activities including interviews, surveys, and site observation which involve a big number of stakeholders (e.g., local authorities, expert from the Vietnam Institute of Energy, rice mill owners, the university in Vietnam, the unsuccesful power plant(s) using rice husk, EVN's respresentative) contribute a crucial part of data collection.

The data collected then becomes the input for analyzing process, with outcome being the anwsers for research questions. Note that these analyses are not totally separated, but complement one another, e.g., the current status of rice husk in An Giang province and lessons learned from the unsuccesful power plant fueled by rice husk are basic for the assessment of the two possible power plants.

The assessment will lead to conclusion in term of technical, economic, environmental and social perspectives. The flowchart below reflects the framework.

3.2. Field study

The field study covers the whole area of An Giang province. Methods to collect data consist of interviews, surveys and site observation. The interviews follow principles and tips from the guidelines Practical Interviewing by Orlando E. Blake (Blake, 2011). Although interviews in person are more preferable, in some cases it is necessary to use phone calls, and questionnaires also can be sent to the respondents via emails.

3.2.1. Interview with rice mill owners

Based on reference to the questions on gasification in Cambodia-SME Renewables (Ahlgren, 2014) and the research aims, questionnaires were prepared during preparation phase and at the beginning of the field trip, with each targeting to a type of stakeholder. They were later adjusted due to real situation and experts'opinion at the field. The questionnaires were written in Vietnamese, and later be translated into English by the researcher, the translations can be seen in the Annex.

Rice mill owners are pivotal respondents for the study. Number of total rice mills in An Giang was reported to be 1000 (see section 2.6.3.). The sample size was determined based on calculation from this value, with consideration for real conditions. According to Taro Yamane formula for calculating sample size

$$n = \frac{N}{1+Ne^2}$$

Where: n is the sample size, N is the population size, and e is the desired level of precision (Isarel, 1992; Yamane., 1967).

On the other hand, due to limitations on time and personnel, as well as difficuties to acquire responses from rice mill owners, the sample size was desired to be between 30-40 (with N = 1000). There were 40 questionnaires issued, with feedback from 38 rice mills (e = 15.9%). Of which, 15 interviews were conducted by the researcher, 20 by the assistants, and the rest was collected by communication via emails. The map below (Figure 27) reflects location of the rice mills surveyed. Note that the red triangles are the chosen ones for the pre-feasibility study.

The rice mills that were selected are at various scale, from small to large. Their locations also cover the whole area where rice industry takes place. The rice mills' identifications were taken from the list of rice companies in An Giang (Vietask, 2014), and from networking with local individuals which was made directly at the field.

Due to time limitation and the fact that local people have advantages in communicating with rice mills, assistance was necessary for the surveys. Four individuals were hired to guide and drive the researcher to the mills (just following addresses was not easy at the field), and to help interview the mills' owners. These assistants had been trained by the researcher prior to the work.

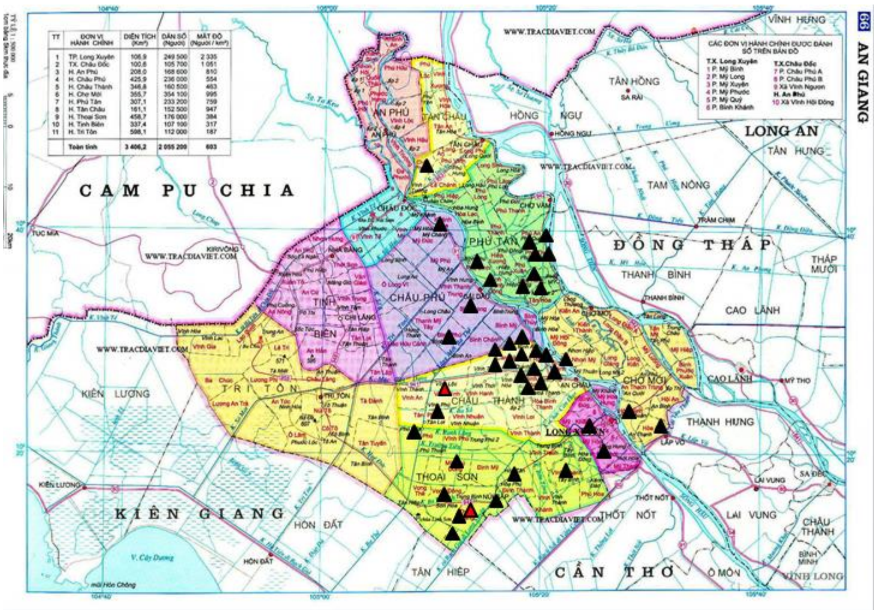


Figure 27: Location of surveyed rice mills on map

For this type of stakeholder, main questions include the mills' capacity, number of operating days, rice husk uses and price for each type of use (if any), enviromental and other issues caused by rice husk, utilization of rice ash (if available), amount and cost of electricity demand, source of hear for drying systems, type of transport for rice and husk including estimated distance and cost, question on the lack of electricity for the business, and their opinion on possessing their own rice husk-based power system.

3.2.2. Interview with the unsuccessful power plant(s)

Lessons learned from the two neighbor countries (see section) lead to two indicators to investigate unsuccessful power plant(s) fueled by rice husk: technical and non-technical issues. The latter consists of economic reason, competition for rice husk, and human resources. Questions for the survey involve installed capacity, technology applied, amount and price of fuel used, transportation of rice husk (type/distance/cost), location of husk supplied, time of operation, wastewater treatment, amount and price of electricity sold, amount and price of rice ash sold, technical problems, market competion for rice husk, lack of trained workers, reasons of failure for power generation from the owner's point of view, and the need for co-generation.

Although a report from the collaboration project (see section 2.7.) stated that there has been one 10-MW plant built yet not operated since it is not profitable, and one 500 kW(e) plant is operated occasionally (Kjellström, 2013), they did not address these plants with sufficient information to find them. A document presented by a renewable energy expert from the Vietnam Institute of Energy (Nguyen, 2013) mentions a list of to-be-built rice husk based power plants in Mekong Delta River, excepts for one already built and being under operation in Can Tho province. It is then identified as Dinh Hai Thermal Power Company at Tra Noc Industrial Zone.

Beucase there was only one unsuccesful rice husk fired power plant that could be found and contact, the investigation of reasons for failure in electricity generation therefore solely relies on this identified plant.

3.2.3. Data collection for the pre-feasibility assessment

Prior to the field trip, various stakeholders were identified for interviews and surveys to be input for the pre-feasibility study. First of all, it is worth obtaining the information of and opinion on rice husk-based energy from the Institute of Energy, Vietnam, as an organisation at central level. Contact to experts at the Institute of Energy in Hanoi, was made before the trip. They were questioned to provide information on current status of rice husk based power industrial units.

Secondly, representative(s) of the responsible party for the development of rice husk based power generation in An Giang is/are needed to present opinion of the local government on the issue. The Vietnamese stakeholders who take part in the collaboration project (see section 2.7.), arecontacted for this purpose. They were supposed to provide detailed information of the project, contacts and supports at the local level. Furthermore, they are able to provide advices on the quesionnaires for local rice mills.

Being the dominant party who is responsible for the national grid and electricity system, EVN's thoughts and policies on electricity generated by rice husk, therefore, are necessary to be included. To be specific, questionnare contains questions to find out what EVN thinks of rice husk based power, whether they consider to buy that kind of energy plant, number of such power plants existed and/or planned-to-be-built, and their information of the 20-plant project. There exists a local branch of the state-owned company in An Giang (EVN SPC An Giang), therefore their opinion is more preferable. However, due to contact at EVN Ho Chi Minh City (EVN HCMC), and the fact that the expected answers are able to collect at general level, a questionnaire was sent to EVN HCMC.

Four rice mills named Ut Hien, Vinh Binh, An Viet, and An Giang Import and Export, were selected to visit based on their apparently expressed interest in power plants using rice husk. Two of them are private companies (Ut Hien and An Viet), while the others two belong to the government (Vinh Binh and An Giang Import and Export). Their quesionnaire is similar to the other rice mills'. However, it requires more details in term of energy consumed in different parts of the processing (drying, dehusking, polishing and whitening, and briquetting/pelleting). Their willingness and conditions for possessing such power systems were also discussed. In combination with information of rice mills who express the same interest from the other interviews, an arevage value of rice production capacity of these potential mills was calculated. The choice of two among all these mills for an pre-feasibility assessment was based on this average figure and type of business.

3.3. Data analysis

Data collected from a big number of rice mills will be processed using software such as Microsoft excel, and analyzed by simple statistical methods, including calculations of proportion and avarage values. The analyses aim at obtaining knowlege on rice husk-related issues, such as logistics, market, prices, and current uses. Table 8 indicates how each parameter is evaluated. The output combined with information obtained from other stakeholders, such as EVN and An Giang's authority, to describe the current status of rice husk in An Giang.

Table 8: Evaluation of data acquired from questionnaires at rice mills

Parameter	Evaluation
Scale of business	Big (≥100000 tonne of paddy/year) Medium (>30000 and <100000 tonne of paddy/year) Small (≤30000 tonne of paddy/year)
Type of business	Private/Public/Other
Capacity of paddy processed	tonne/year
Amount of husk produced	tonne/year
Day of operation per year	day/year
Use of rice husk	Burn/Sale*/Briquette/Pellet/Dump/Other
Amount of husk according to uses	tonne/year
Price of rice husk-based product	VND/tonne
Environmental problem from rice husk	Dust/Smell/Aquatic pollution/Other
Amount of electricity used	kWh/year
Source of heat for drying system (if available)	Electricity from national grid/Husk/Other
Transport type for rice/husk	Waterway/Roadway/Railway
Estimated distance of rice/husk transported	km
Lack of electricity	Yes/No (if yes: hour/year)
Interest in possessing rice husk based power plant	Yes/No

*rice husk is sold as raw material

Table 9: Evaluation of data acquired from questionnaire(s) at unsuccessul power plant(s)

Parameter/Indicator	Evaluation
Installed capacity	MW/kW
Operation time	Hour/year
Technology used	Gasification/Combustion/Other
Co-generation	Yes/No
Amount of rice husk used	Tonne/year
Amount of electricity produced	kWh
Amount of steam/heat produced	kg
Price of electricity producted	VND/kWh
Price of steam/heat produced	VND/kg
Wastewater	Treated/Dumped to river/Other
Amount of rice ash sold	Tonne/year
Price of rice ash sold	VND/tonne
Technical issue	Electricity generation process/Wastewater treatment
Economic issue	Low benefit/Non-benefit/Other
Competition for rice husk	Rice husk availability
Human resource	Lack of trained worker(s)

The findings from the unsuccessful rice husk-based power plant(s) become an important reference for technical and non-technical solutions for the new power plants of the same kind. Table 9 shows different parameters and indicators and the ways to evaluate them. Note that in case of cogeneration of steam and power, a ratio of 3.73 tonne steam produced per tonne of rice husk (at 52 kg/cm^2, 450^oC) (UNFCCC, 2010) is used.

3.4. Pre-feasibility assessment

The overarching objective of this assessment is to address technical, economical, social, and environmental concerns of two possible rice husk-based power plants which would be locate at the two chosen rice mills. The following text decribes methods and procedure to deal with each aspect.

3.4.1. Technical perspective

Regarding to technical system, the outcome of this research focus only on main features of the possible power plants, e.g., the choice between gasification and combustion, along with its key equipments, and does not take into account which type of other components of the co-generation systems.

3.4.1.1. Size of the plant

The size of the plant is limited mainly by the rice husk supply at the rice mills. Availability of rice husk as fuel resource and resulting power plant is calculated by the formula (Bergqvist & Wårdh, 2007):

*Available amount of husk for power production = Amount of processed paddy * HPR * Husk availbility factor*

$$P_{size} = \frac{Available\ amount\ of\ husk\ for\ power\ production}{SFC * Operating\ hours}$$

Where:

HPR = Husk to paddy ratio

P_{size} = Size of power plant [kW]

SFC = Specific fuel consumption

Operating hour = given as equivalent number of full load hours

In this research, HPR is set at 20%. For gasification of rice husk alone, SFC has been reported to be in the range of 1.7-1.9 kg/kWh for electricity generation capacity of 800 kW or higher. However, for low capacity (about 200 kW), the SFC is reported to be as high as 3.5 kg/kWh (Buragohain, et al., 2011). The value of SFC is refered from the previous assessment of utilizing rice husk for heat and power production in Vietnam in 2007 (Bergqvist & Wårdh, 2007) which based on a conservative estimation of net efficiencies (delivered power to consumer), namely 1.8 kg husk/kWh, implying that each tonne of husk is able to produce roughly 555 kWh of electricity.

If the possible power plants only serve the rice mills who own them, the equivalent number of operating hours per year is assumed to be 5000, corresponding to a load factor of 0.57 (Bergqvist & Wårdh, 2007). This amount of 5000 working hours also was used in the previous pre-feasibility study in 2004 (PREGA, 2004). On the other hand, if the plants are designed to supply the grid with power, the equivalent number of operating hours per year can be 8000 (Bergqvist & Wårdh, 2007). Because in this research, only extra electricity produced is considered for selling, the value of operating hours is thus set to be 6000 in case of generating extra power to sell to the grid. Since the husk is directly supplied from the mills to their power plants, husk availability factor equals to 1. These values are the same for both plants.

3.4.1.2. Heat demand for drying systems

In case of co-generation of heat and electricity, it is necessary to determine the heat demand for the dryers. In this research, energy consumption for drying systems is assumed to account for 89% of total energy demand of rice mills who performs a 5-step paddy milling process (cleaning, drying, milling, whitening, polishing, sorting) (Basappaji & Nagesha, 2013). Moreover, in case the studied rice mill utilize its rice husk as fuel for drying systems, a ratio of 120 kg rice husk consumed for 1 tonne of paddy (equal to 1507 MJ/tonne or 419 kWh/tonne, with the heating value being 3000 kcal/kg) is used (Basappaji & Nagesha, 2013).

On the other hand, if rice husk briquette is utilized to feed drying sytems at the mills, it is assumed that the briquette's heating value stands at 4000 kcal/kg (KhiHoa, 2011). This is in accordance with information provided by many rice husk briquette produders in Vietnam which falls mostly between 3700 - 4100 kcal/kg (Weiku, 2014), with 1 kWh = 3,6 MJ = 860 kcal. The energy consumption by briquette machines has been found to be about 175 kWh (field survey in 2006) to produce one metric tonne of rice husk briquette fuel at producer level (UNEP, 2004), and it often takes 1.2 tonne of rice husk to be made into 1 tonne of briquette.

3.4.1.3. Fuel transportation

In both cases, the rice mills are supposed to be able to construct their power plants at the same areas. Nevertheless, if transportation is needed, due to the abundant canals and rivers in the region and cheap price for water transportation, it is likely to expect the possible plants take advantages of waterway to carry rice husk.

3.4.1.4. Technology

Three main factors influence the choice of suitable technology are rice husk availability, heat-to-power (H:P) ratio needed, and fuel characteristics. Firstly, biomass power plants tend to be limited in size, due to the limited amount of available fuel. Based on real-life capacities of the two selected rice mills, energy conversion method will be defined. If the size of the plant is less than 1MW, inclusively, gasification is selected. Otherwise, combustion is chosen.

The other factor, fuel characteristics, mostly affects which equipment is more suitable. An analysis of rice husk concerning moisture content, heating value, homogeneity, and ash content can be seen in Section 2.3.3. Based on the three schemes mentioned in that section, in case of gasification, the schemes where rice husk is gasified in a gasifier, and then produced gas is led to gas turbine or IC engine for power generation, is applied. On the contrary, the third scheme which uses a furnace (fluidized bed/grate type) and steam turbine is carried out for combustion case.

For combustion technology, if H:P ranges between 4 - 14.3, back-pressure steam turbine is selected, while smaller ratios take extraction-condensing steam turbine as the equipment. Regarding to gasification, it is necessary that the heat-to-power ratio does not excess 4.5.

3.4.2. Economic perspective

All monetary values are in VND or USD equivalent. The currency exchange rate is taken from the state bank of Vietnam, that is 21100 VND = 1 USD, retrieved on 27th May, 2014.

3.4.2.1. Costs

Investment cost

Investment cost can be broken down to costs of equipments, construction, and others (such as transmission). The cost of complete solid fuel co-generation plants varies with many factors, with fuels handling, pollution control equipment and boiler cost all being major cost items. Because of both the size of such plants and the diverse sources of the components, solid fuel cogeneration plants invariably involve extensive system engineering and field labor during construction. Typical complete plant costs run upwards of 2000-3000 USD/kW, with little generalization except that for the same fuel and configuration, costs per kW of capacity generally increase as size decreases (E&E Analysis, 2008).

Equipment cost

The two main components include a biomass-fired boiler and a steam turbine in combustion case. According to (Nguyen, 2013), equipment cost for rice husk using Circulating Fluidized Bed (CFB) is between 1800-2100 USD/kW. The capital cost of a back-pressure turbogenerator complete with electrical switchgear varies from about 900 USD per kW for a small system (150 kW) to less than 200 USD/kW for a larger system (> 2000 kW) (Department of Energy, 2012). The range has been reported by The World Alliance for Decentralized Energy (WADE) as between 400-1500 USD/kW (WADE, 2014). Installation costs vary, depending upon piping and wiring runs, but they typically average 75% of equipment costs (Department of Energy, 2012). Therefore, total installed costs for combustion using a furnace (fluidized bed/grate type) and a back-pressure sytem are ranged between 3675-5775 USD/kW. Meanwhile, cost of gasification systems for electricity generation can be seen in table.

Table 10: Typical capital costs (total installed costs) of biomass power technologies (IRENA, 2012)

Equipment	Price (USD/kW)
Stoker boiler	1880 – 4260
Bubbling and circulating fluidized bed (CFB)	2170 – 4500
Fixed and fluidised bed gasifiers	2140 – 5700
Stoker CHP	3550 – 6820
Gasifier CHP	5570 – 6545

Due to these references, in this research, the total investment cost for combustion and gasification system is set at 3700 and 5600 USD/kW, respectively.

Contruction and other investment costs

A pre-feasibility assessment of a rice husk fired power plant in An Giang in 2004 resulted in a total investment cost of 935000 USD/0.5MW, of which equipment cost was 785000 USD. By considering the year 2014 as a "Future Value" (FV) of the value in 2004 ("Present Value" or PV), contruction and other costs relating to initial investment can be brought to the current rate by the formula

$$FV = PV * (1 + i)^n$$

Where:

i = interest rate; n = number of years in between two time points (AccountingCoach, 2004)

The graph in Figure 28 reflects the changes of interest rate for the period 1997-2012. The rate in 2013 and 2014 are approximately 8 and 7%, respectively (Trading, 2014). From values extracted from the graph and the data in 2013 and 2014, an avarage interest rate is calculated, resulting in 8.4%. Calculation indicates a cost of 672 USD/kW, which is applied in this sutdy.

In addition to the technical investment cost, 10 % of the investment is added for financing costs as expenses. This ratio is learned from the PFS in 2004 (PREGA, 2004).

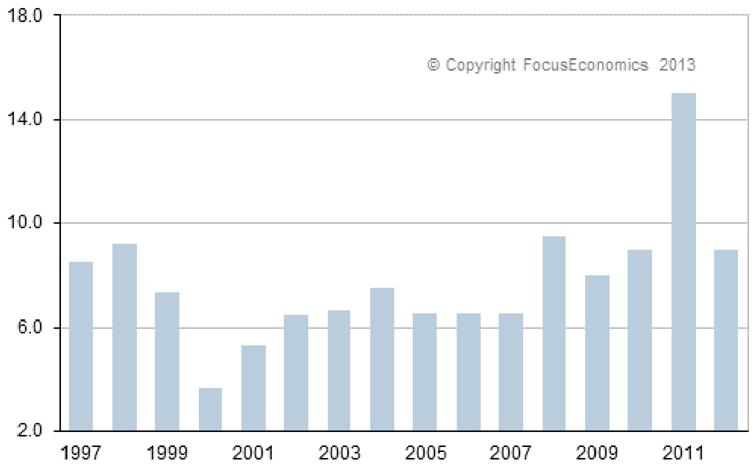


Figure 28: Vietnam Interest rate for the period 1997-2012 (Focus, 2014)

O&M cost

Operation cost consists of labor cost amd maintenance cost. Based on surveys, avarage salary in Vietnam is determined as monthly 8150000 VND (or 385 USD/month) at Median level (Salary, 2014). Number of workers will be taken from calculation in social aspect section. The total labor cost per year is then be formulated:

$$\text{Labor cost} = 385 * 12 * \text{Number of workers}$$

The PFS in 2004 assumed that annual maintenance cost is accounted for 3% of total equipment cost (PREGA, 2004), that value is also applied in this research. Since rice husk will be supplied by the rice mills themselves, there is no cost for fuel is included, it is the same for transportation cost of the husk. Additionally, an increasing rate at 4% per year is used to calculate future cost.

Lost benefit of rice husk sold

When rice husk, the whole production or part of it, is utilized for power and heat production, the benefits acquired from selling the argo-residue as raw husk or its by-products are lost to the rice mills. This losing benefit is considered as a "cost", and is calculated as follows

*Lost benefit of raw husk/by-product sold = Amount of raw husk/by-product lost * Price of raw husk/by-product*

Amount of raw husk or that of the by-product(s) lost is based on the amount of husk used for electricity generation, and the proportion of different uses of rice husk at the rice mills at the moment.

3.4.2.2. Benefits

Cost of electricity purchased (energy cost saving)

This cost is calculated by the following formula:

*Energy cost saving = Amount of electricity purchased * Price of electricity purchased*

Without the power plants, amount of electricity which would be purchased in the future is assumed to be the same as at the moment, while there is an increasing trend in price of electricity sold by EVN.

According to EVN's electricity tariff in 2014 (EVN, 2014) and information presented by Nguyen, M.H. (Nguyen, 2014), this price is currently at 0.06 USD/kWh. The Vietnam Power Development Plan VII (Vietnam, 2011) states that the government will raise the electricity tariffs step by step to 8-9 US cents per kWh by 2020 in order to bring the electricity tariffs closer to the market price to ensure reasonable returns for the investors. Thus, an increasing rate is calculated, resulted in 6.9% per year. The table below summarizes calculated prices of electricity until 2034.

Table 11: Calculated price (USD/kWh) of electricity purchased from EVN till 2034

Year	Price	Year	Price	Year	Price
2014	0.060	2021	0.096	2028	0.154
2015	0.064	2022	0.103	2029	0.164
2016	0.069	2023	0.110	2030	0.176
2017	0.073	2024	0.117	2031	0.188
2018	0.078	2025	0.126	2032	0.201
2019	0.084	2026	0.134	2033	0.215
2020	0.090	2027	0.144	2034	0.230

Benefit from rice husk sold as by-product

As stated earlier, rice husk can be made into briquette, pellet, or sold as raw material. Benefit gets out from these uses of the husk is determined by the formula:

*Benefit of raw husk/by-product = Amount of raw husk/by-product * Price of raw husk/by-product*

Both amount and price of different types of by-product are obtained from analyzing the questionnaires.

Benefit from rice ash produced

Rice ash is valuable and therefore can contribute to total benefit of the power plants. Price of the ash is based on experience of the unsuccessful power plant(s) surveyed. This study applies the data from (Bouzoubaâ & Fournier, 2001), each tonne of paddy can produce about 200 kg of husk, which on combustion produces about 40 kg of ash, thus the ratio of ash to husk is 0.2. Therefore benefit out of rice ash is formulated as follow:

*Benefit of rice ash sold = Available amount of husk for power production * 0.2 * Price of rice ash sold*

Benefit from extra electricity sold

Based on the recent Decision on 24th March 2014 regarding combined heat and power projects, the value of 1220 VND/kWh (excluded 10% VAT, equivalent to 5.8 US cents/kWh) is applied for extra electricity produced and sold to the national grid. Exchange rate is projected based on historical data shown in the graph below. Within a decade, the rate was grown by approximately 31.25%, making an increase of 3.125% yearly.

Figure 29: USD/VND exchange rate between 2005-2014 (Trading, 2014)

The following formula calculates this type of benefit annually (from 2015 and outwards)

*Benefit of electricity sold in year n = Amount of extra electricity in year n * 0,058*[1+(n-1) r_{uv}]*

Where: r_{uv} is the USD/VND exchange rate

The amount of extra electricity equals to total electricity produced at the power plants minus the rice mills' electricity demand. The former is determined by size of the plants, while the latter is extracted from questionnaires.

Benefit from CERs

This benefit is calculated by the formula:

*Benefit from CERs = Amount of CERs * Price of CERs*

Determining amount of CERs for the whole life time of the power plants is discussed in the section 3.4.4.

Price of carbon credit has been declining for significantly for the 4 years (see section 2.7), thus it is difficult to project its fluctuation in the future. Therefore, in this research, carbon price is identified based on EUA ETS at the end of the described trendline, namely €3.90 or 5.3 USD per tonne, with an assumption that the price will stay at this level for the whole life time of the project.

3.4.2.3. Profitability

Net present value

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows (Investopedia, 2014). NPV is used in capital budgeting to analyze the profitability of an investment or project. A project is profitable if it has a positive NPV and the more NPV gets, the more profitable the alternative is (Bergqvist & Wårdh, 2007).

The following formula is used for calculating NPV:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

Where:
C_t = net cash inflow during the period
C_o= initial investment
r = discount rate
t = number of time periods
T = time life of the project

Regarding to discount rate, Vietnam had an average central bank discount rate of 9.30 % in the period of 5 years (2007 to 2012) (Mecometer, 2013). Thus this value is applied for calculations. NPV is determined for the whole life time of the plants (till 2034).

Payback period

Payback period is used to determine the length of time it will take to recoup the initial amount invested on a project or investment. The payback period formula is used for quick calculations and is generally not considered an end-all for evaluating whether to invest in a particular situation (Finance, 2014).

Payback period = Initial Investment/Annual net benefit

Annual net benefit = total annual benefit – total annual cost

3.4.3. Social perspective

This aspect of job creation has not been calculated in quantitative term. It is, therefore, a new contribution of the research.

Thermal power plants, if built and operated, will create jobs for local and non-local individuals. A PFS on Biomass Power Plant Fort Bragg in California, 2007 indicated that one could expect 5 to 6 direct jobs created per 1MW (North Coast, 2007). Thus the number of jobs created by the possible power plants can be calculated as following:

$$\textit{Number of jobs} = 6 * P_{size}$$

3.4.4. Environmental perspective

In this study, positive impacts on the environment created by the rice husk-based power plants are based on the assumption that since electricity produced by these plants will substitute that produced by other fossil fuel based power plants, and because electricity production from biomass is considered as carbon neutral, there is CO_2 emission reduction (or CERs). This study neglects the carbon emissions that probably appear from the fact that when the part of rice husk which normally sold to use for other purposes in other places, now is utilized for power generation. As a consequence, those places would need to have alternative energy resources to replace the amount taken from the rice husk. Depending on these alternative options, CO_2 emission may be emitted. Because this fact is considered as beyond the boundaries of the reasearch, the results on environmental aspects are not comprehensively evaluated.

Every year the International Energy Agency (IEA) provides information of emission per electricity production by country. CO_2 emissions from fossil fuels consumed for electricity generation, in both electricity-only and combined heat and power plants, divided by output of electricity generated from all fossil and non-fossil sources. Both main activity producers and autoproducers have been included in the calculation (IEA/OECD, 2013). Table 11 is derived from their report in 2013. Based on the figures between 2004-2011, an average emission intensity is calculated for Vietnam, namely 0.425 kg CO_2/kWh$_e$.

Table 12: CO_2 emitted per kWh$_e$ in Vietnam in some years (IEA/OECD, 2013)

Emission	2004	2005	2006	2007	2008	2009	2010	2011
gCO_2/kWh	438	447	435	426	406	384	432	429

The yearly amount of CERs is determined by the following formula:

*Amount of CERs = 0.425 * Total electricity produced by the rice husk-based power plant*

This annual amount is multiplied by the life time of the projects (20 years) to obtain the total CO_2 emission reduction acquired by the existence of the rice husk-based power plants. To put the results in more meaningful terms, reduction of CO_2 emission is converted by the Greenhouse Gas Equivalencies Calculator (EPA, 2014) into real-life examples.

3.4.5. Comparison of cases

In order to compare profits of different uses of rice husk in term of economic, social and environmental values, BAU status and 4 cases are taken into consideration for each power plant. Business-as-usual (BAU) implies current uses for rice husk at the mills at the moment.

There are 4 alternatives, distinguished by annual benefits, to be considered as described below. Note that the 4 cases have only two technical solutions: the first solution is applied in case 1 and 2, and the second one in case 3 and 4. Case 2 and 4 infact are used for the sensitivity analysis on the importance of CERs to the profitability of the projects.

Case 1: 100% rice husk is utilized for the co-generation systems, with extra electricity sold to the grid and CERs being sold.

Case 2: 100% rice husk is utilized for the co-generation systems, with extra electricity sold to the grid and without CERs being sold.

Case 3: Part of rice husk is utilized to produce power and heat to satisfy the mill's energy demand, the spare husk is sold as it is treated in BAU, with CERs being sold.

Case 4: Part of rice husk is utilized to produce power and heat to satisfy the mill's energy demand, the spare husk is sold as it is treated in BAU, without CERs being sold.

Table 13: Components for net benefit calculations of 4 cases

Case	Annual Cost	Annual Benefit
1	(1) O&M (2) Lost benefit of raw husk/by-product sold	(1) Energy cost saving, (2) Extra electricity sold, (3) Rice ash sold (4) CERs sold
2	(1) O&M (2) Lost benefit of raw husk/by-product sold	(1) Energy cost saving, (2) Extra electricity sold, (3) Rice ash sold
3	(1) O&M (2) Lost benefit of raw husk/by-product sold	(1) Spare husk sold, (2) Energy cost saving, (3) Rice ash sold, (4) CERs sold
4	(1) O&M (2) Lost benefit of raw husk/by-product sold	(1) Spare husk sold, (2) Energy cost saving, (3) Rice ash sold

4. Results

4.1. Current status of rice husk in surveyed mills in An Giang

4.1.1. Scale and operation of business

First of all, the rice mills were sorted by paddy processing capacity. As it can be seen from the table, small scale businesses hold the lion share, namely 76.3% (or 29 mills) of the total rice mills surveyed in An Giang. The mills at medium and large size are responsible for 10.5% and 13.2%, respectively. There are 35 out of 38 enterprises in the sample being private companies (approximately 92%), one is a joint venture company, and 2 belonging to the government (roughly 5.3%).

Table 14: Number of rice mills according to scale

Capacity of paddy processed (tonne/year)	Number of mills	Percentage	Proportion based on scale
300	1	2.6%	76.3%
1000	2	5.3%	
1500	1	2.6%	
2000	2	5.3%	
3000	1	2.6%	
3500	1	2.6%	
4000	1	2.6%	
5000	3	7.9%	
6000	2	5.3%	
7000	1	2.6%	
10000	4	10.5%	
11000	2	5.3%	
17000	1	2.6%	
20000	2	5.3%	
30000	5	13.2%	
40000	1	2.6%	10.5%
50000	2	5.3%	
72000	1	2.6%	
100000	2	5.3%	13.2%
120000	1	2.6%	
150000	2	5.3%	

The amount of paddy processed at these rice mills totalled 1.15 million tonnes, while the total amount of husk produced is 0.22 million tonnes, accounted for 19.2%. During the whole year, the rice mills operate on average 270 days. However, this operating time differs from one scale to another, with large mills working for 360 days per year, in comparison with medium (300 days) and small (246 days) businesses.

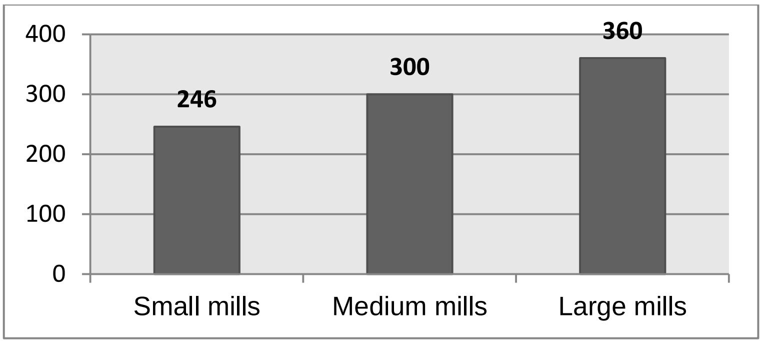


Figure 30: Operating days per year of different scale business

Total electricity consumption at those sampled stands on average 41.5 GWh per year, equals to a value of roughly 36 kWh/tonne of paddy processed (excluded energy required for drying).

4.1.2. Issued caused by rice husk

Twenty seven out of 38 rice mills mentioned dust to be enviromental issue. Nine respondents also cite that rice husk causes problems for their storage area, while only three thinks that the residue makes negative impacts for the water resource. However, all the mills surveyed consider environmental issues of rice husk to be minor.

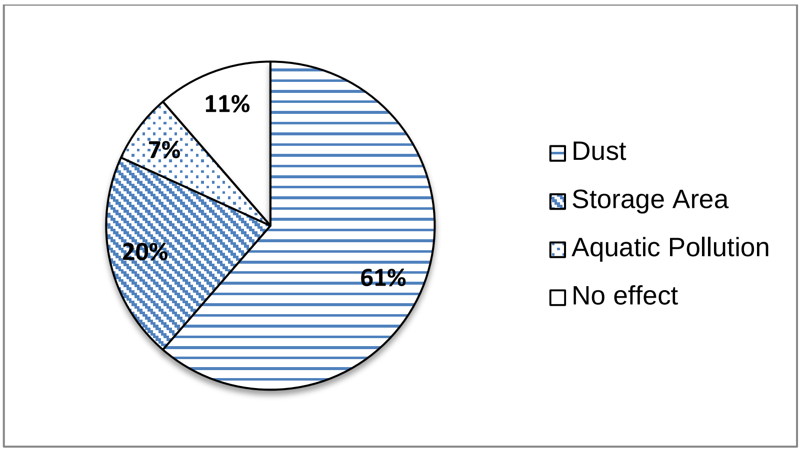


Figure 31: Rice husk-caused issues

4.1.3. Current uses of rice husk

Rice husk uses at the sampled mills include directly burning for drying systems, briquette making, and selling. Due to the mills' response and site observation, there is no unused husk which is wasted. The main way to deal with rice husk (roughly 55%) is to sell it as raw fuel or material, mostly to drying owners. Other buyers are for example brick kiln making business and households (for cooking). Nearly another quarter of the husk becomes fuel input for the drying systems at the mills for their own drying systmes. The rest is made into briquettes, as a by-product to be sold. The table below summarizes the amount of rice husk in accordance with their usage.

Table 15: Amount of rice husk for different uses

Rice husk	Amount (thousand tonne/year)
Total	221.3
Burned directly for drying	52.8
Briquetted	46.9
Sold	121.6

Rice husk is treated differently depending on scale of the mill. Although all mills sell the most part of husk as raw material or fuel, small business has the biggest portion, namely 64%, which is more than medium and large enterprises by 22% and 10%, respectively. Large rice mills, on the other hand, burn an amount of husk that is nearly 4 times as much as used at small ones (32% compared with 9%), and more than the amount burned at medium size mills by 8%. Large mills also do not appear to favor briquetting making, with only 13% husk used for this purpose, making it the smallest portion. Medium mills have a more balanced contribution of rice husk uses, with the residue burned, briquetted and sold being 24%, 34% and 42%, respectively.

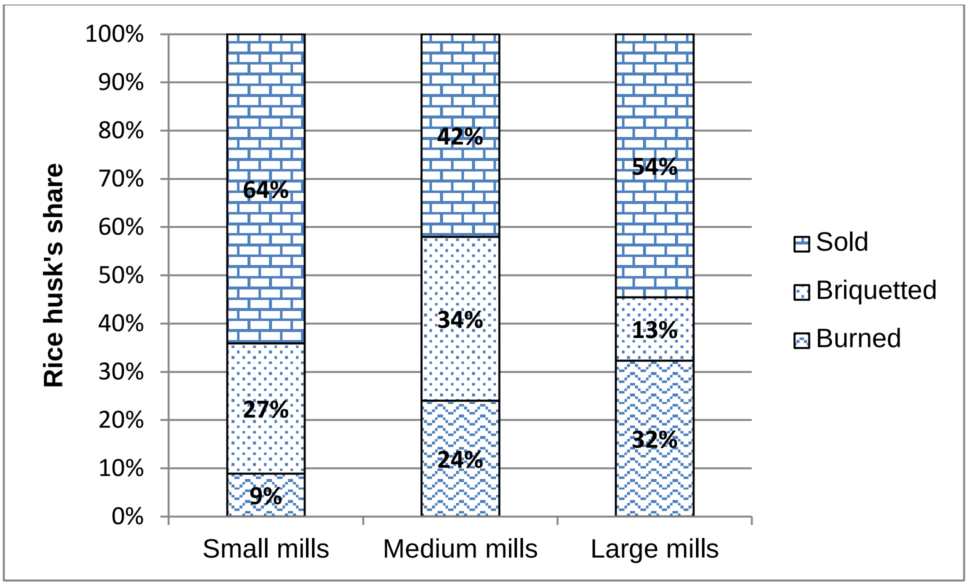


Figure 32: Contribution of rice husk uses based on scale of business

Burning rice husk to supply for drying systems appears in 12 rice mills, accounted for 32%. Meanwhile, roughly a quarter of the sample (10 mills) involves in briquetting business. Raw husk is sold as material or fuel is the most popular in the surveyed rice mills, with 32 enterprises (approximately 84%) dealing with the biowaste this way.

Table 16: Contribution of rice husk uses based on number of mills

Form of use	Number of mills	Percentage
Burning directly	12	32%
Briquetting	10	26%
Selling as raw husk	32	84%

4.1.4. Possession of drying system

Half of the rice mills (50%) possesses their drying system(s). This ratio increases in accordance with the mill size, in particular only 41% of small mills owning dryers, while it is 75% at medium size, and up to 80% at larger scale. In all cases, heat demand is provided by husk, either as a direct fuel or as briquette. Nearly 80% drying process utilizes raw husk, being the dominant use.

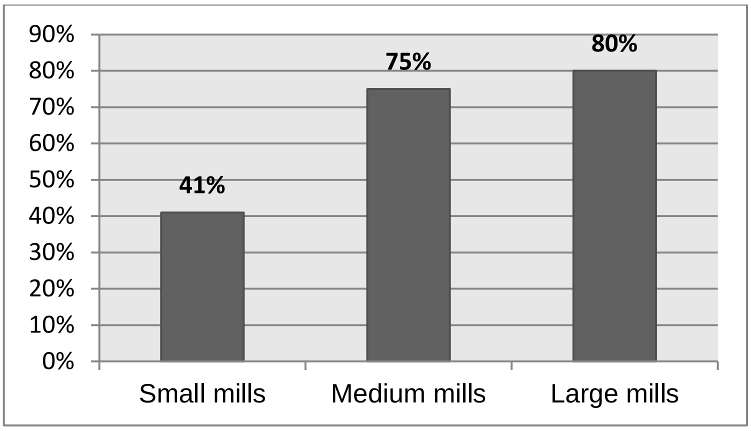


Figure 33: Ratio of possessing drying system at different mill sizes

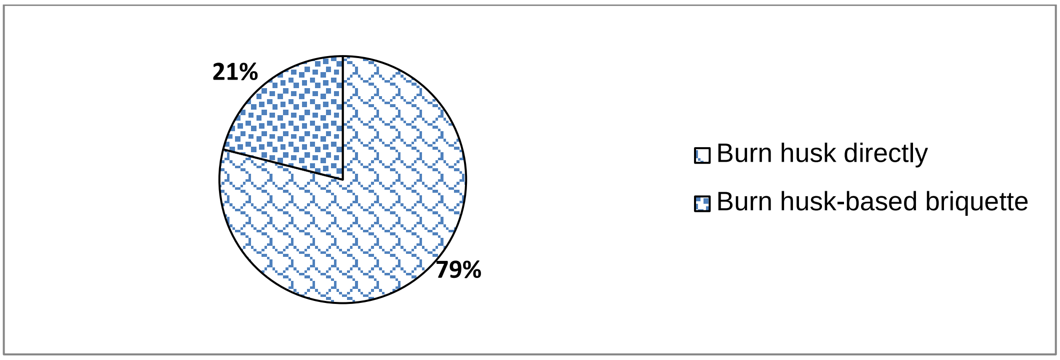


Figure 34: Utilization of rice husk for drying system

4.1.5. Price of rice husk

Despite the fact that pellet form could be sold at 1400000 VND/tonne or 66.4 USD/tonne, no rice mills surveyed produce this type of product. Apart from it, rice husk which is made into briquettes has the highest value, being averagely 940000 VND/tonne, or 44.5 USD/tonne. Based on several rice mills' information, the market for rice husk briquettes has been active for the past 6 years. The price of husk sold as raw fuel fluctuates significantly between 125000 and 600000 VND/tonne (5.9-28.4 USD/tonne), with the average value standing at approximately 317000 VND or 15 USD per tonne of husk.

Rice husk ash created by burning the husk is often given to local farmers for no monetary value.

4.1.6. Transportation of rice and husk

All of the surveyed rice mills are using waterway, roadway or a combination of both to transport rice and husk. The graph below shows proportions of each type of transportation according to the rice or husk. As it can be clearly seen from the graph, waterway is the dominant type to carry rice and husk, contributes to 72% (for rice) and 66% (for husk), roughly 4 times more than using roadway alone. Almost one tenth of rice (9%) is transported by both road- and waterway, while 16% of husk is carried by these ways.

In term of both items, estimated distance for tranportation is within a 150-km radius from the rice mills. Cost of transportation varies dramatically, therefore an average figure can not be made.

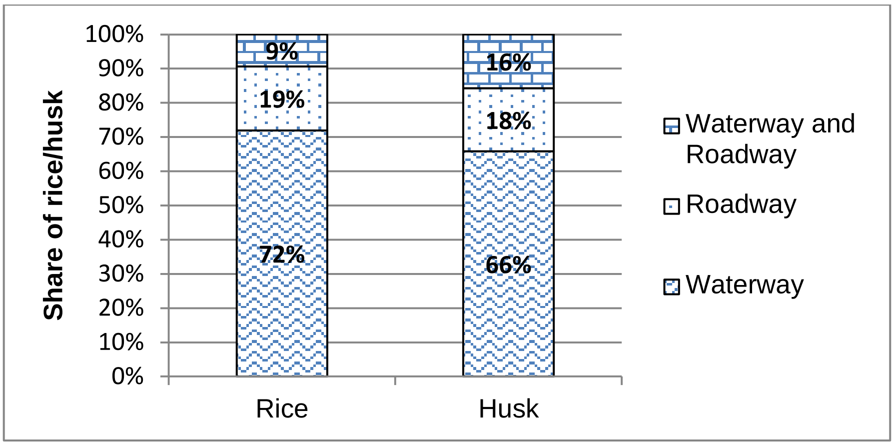


Figure 35: Transportation types of rice and husk

4.1.7. Lack of electricity supplied

Seven rice mill owners state that sometimes electricity is slightly insufficiently supplied. To be specific, around the year, the mills are out of power taken from the natonal grid for a period ranging from 160 to 392 hours, with an average value of 267 hours. Under the circumstances, they usually take the days off, or in some rare urgent cases (e.g., high time of the production) small diesel fired power machines would be used. The application of these power machines is carried out at medium and large enterprises

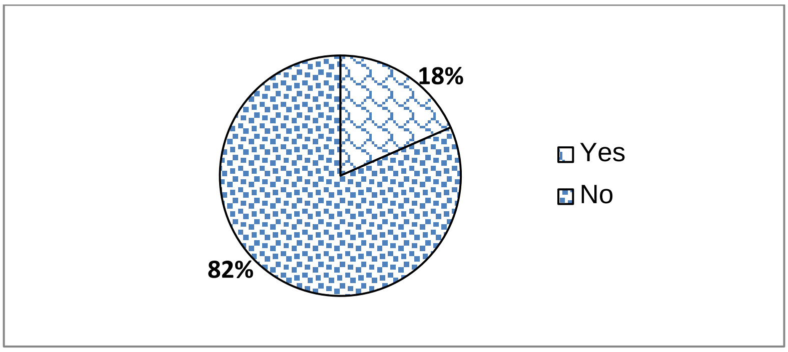


Figure 36: Lack of electricity at the surveyed mills

4.1.8. Interest in rice husk-based power plants

Regarding to the mills'opinion on owning power plants fired by rice husk, only 3 out of the sample express this intention, one gives no feedback on the question. Those interested rice mills possess capacity of 50000, 72000, and 150000 tonnes of paddy processed per year, respectively. Two of them are at medium scale, the other being one of the biggest rice mills surveyed.

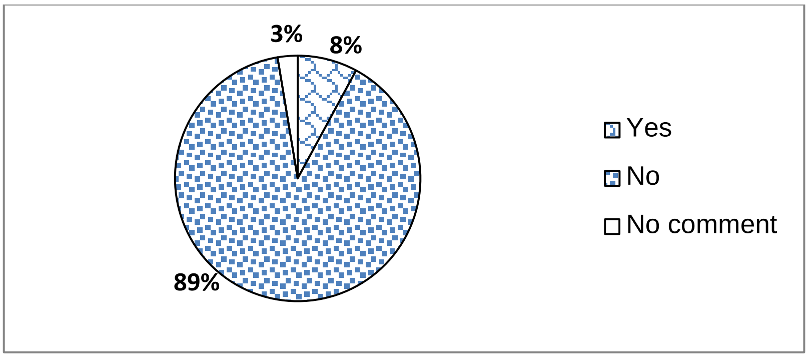


Figure 37: Opinion on possession of rice husk based power plant

4.2. Investigation at the unsuccesful rice husk-based power plant

4.2.1. Introduction of the power plant

By local informants and deriving from a few documents, Dinh Hai Thermal Power Company (DHTPC) at Tra Noc Industrial Zone in Can Tho province, part of the Mekong Delta, was identified as the owner of the unsuccessful power plant fueled by rice husk. Its location can be seen on the map below.

4.2.2. Features

It is a power plant using combustion technique to co-generate steam and power. Designed power capacity is 2MW (2011-2012) and 9MW (2013-2014), while installed steam capacity was at 20 tonne per hour, with an orginal plan to expand it to 70 tonne/hour (Truong, 2012). The plant first run in 2010, and from that point on, only steam had been sold to several factories in the Industrial Zone. However, the plant had not been operating for 6 months up to the study time (March, 2014), due to its unability to continue selling the heat to other factories who had been its clients. Some of the other industries stopped working because of economic downturn.

Table 17: Main features of DHTPC's power plant

Feature	Figure
Capacity	2 - 9 MW_e 20 - 70 tonne of steam/hour
Operating time	7200 hour/year
Rice husk consumption	50 tonne/day
Cost of rice husk	23.7 USD/tonne
Cost of rice husk transportation	2.4 USD/tonne
Rice husk ash production	5 tonne/day
Benefit of rice husk ash	9.5 USD/tonne
Benefit of steam produced	28 USD/tonne

Under operation, it consumed about 50 tonnes of husk/day, produced roughly 5 tonnes of ash each day which was sold to farmers at 200000 VND/tonne, or 9.5 USD/tonne. The husk was bought at 500000 VND or 23.7 USD per tonne from rice mills in Thot Not (see where the red star marks on the map), where is about 30 km from the location, and then transported to the plant using the river Hau. Price of steam was 600 VND/kg, or 0.028 USD/kg. Husk was transported from Thot Not (see where the red star marks on the map), where is about 30 km from the location. Transportation cost was 50000 VND/tonne, or 2.4 USD/tonne. All around the year, the plant operated for 7200 hours, equal to 300 days. The table summarizes the plant's main characteristics.

4.2.3. Analysis and observation

If the plant opereated, daily benefit would be the values of steam and ash sold. Assumed that all steam produced was purchased by other factories, the benefit then was 45.7 USD from ash (ash content accounted for 20% of the husk) and 5303 USD from steam. Known cost includes cost for purchasing rice husk and its transportation, totalled 1305 USD/day.

Based on observation at the plant and the owner's response, although there is a treatment system for wastewater, it is usually disposed straight to the river Hau which locates next to the construction. In the owner's opinion, treating the effluents is uncomplicated.

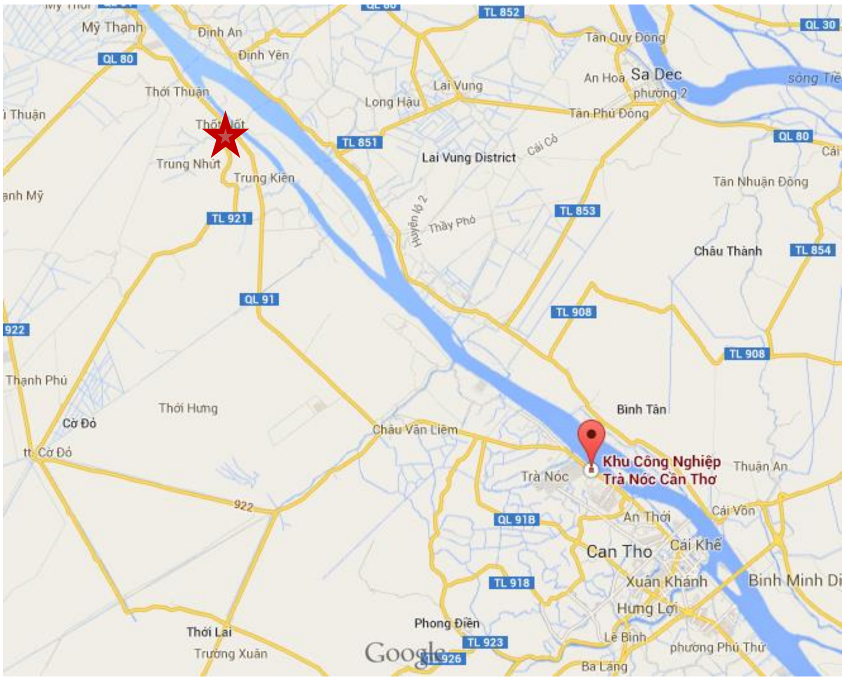


Figure 38: Location of Dinh Hai Thermal Power Company and its rice husk suppliers

4.2.4. Issues

No technical issue related to power generation process is mentioned. Because the wastewater treatment system did not work, it was not a prolem neither.

From the owner's point of view, low level of the price of electricity sold leading to no profit was the main cause preventing the plant from generating power. Furthermore, rice husk supply was not stable, since the plant met competition in use with other buyers.

Human resource did not cause any difficuties, thus lack of trained workers was not a reason for the failure of the power plant.

5. Pre-feasibility assessment of the two possible plants

Based on 7 rice mills who have a high potential for owning rice husk-based cogeneration system due to their interest, an average paddy capacity is calculated among them, resulted in roughly 84000 tonne of paddy processed per year. Thus, the two mills are selected have capacity more (10000 tonne/year) and less (50000 tonne/year) than this value. The bigger one's name is Ut Hien, and the other is called Vinh Binh.

5.1. Description of the two rice mills

The two rice mills chosen are indicated by red triangles on the map, with Ut Hien locating in Thoai Giang Commune, Thoai Son District, and Vinh Binh Food One member Limited Liability Company (Vinh Binh) placed in Vinh Binh Commune, Chau Thanh District. The table below summarizes their main features extracted from the questionnaires.

Table 18: Main features of the two rice mills, Ut Hien and Vinh Binh

Feature	Unit	Ut Hien	Vinh Binh
Total area	m^2	20000	15000
Scale of business		Big	Medium
Capacity of paddy processed	Tonne/year	100000	50000
Amount of husk produced	Tonne/year	20000	10000
Day of operation per year	day	360	360
Use of rice husk and its amount		35% Burn 65% Sale	50% Burn 25% Sale 25% Briquette
Price of rice husk-based product	USD/tonne	26.0	26.0 (Sale) 42.6 (Briquette)
Environmental problem from rice husk		Dust	Dust
Amount of electricity consumption	GWh_e/year	3.30	2.88
Processes powered by the national grid		Drying, dehusking, whitening and polishing	Dehusking, whitening and polishing, briquetting
Source of heat for drying system		Husk burned directly Or electricity from the national grid (8% of total electricity consumption)	Husk burned directly
Rice husk used for drying system	tonne	7000*	5000*
Electricity for drying system (419 kWh_{th}/tonne of paddy)	GWh_e GWh_{th}	0.26* (from the national grid) 41.90* (from rice husk)	 21.00
Amount of electricity used for briquetting system	GWh_e		0.36*
Rice transportation		Waterway	Waterway
Estimated distance of rice transported	km	70	50
Husk transportation		Roadway	Waterway
Estimated distance of husk transported	km	70	50

* calculated value

Ut Hien is a large-size private company who locates on an area of 20000 m^2 in Thoai Son Commune. Ut Hien also has its sister mills that are next to it in the same area. With paddy processing capacity being yearly 100000 tonnes of paddy, the rice mill produces roughly 20000 tonne of rice husk during its 360 days of operation per year. Although the husk not only causes environmental issue, namely high concentration of dust in the air, but also contributes to the mill's cost of storage, it is not considered as a serious problem.

On the other hand, Vinh Binh is a medium-scale rice mill, not only smaller in size but also in land area, in comparison with Ut Hien. The mill has a plan to expand its capacity in the future. At the moment, every year it mills about 50000 tonnes of paddy, produces an amount of 10000 tonnes rice husk. Roughly half of the rice husk is pressed into briquette form, and then approximately half of the briquettes is used as fuel for the drying system within the place, while the other half is sold to various buyers.

All data collected from the two rice mills (table 18) is the input for calculations that are clearly written in section 3.4. The results and assessment are shown in the next parts for each power plant.

5.2. The 4 cases of the power plant at Ut Hien rice mill

Technology, social and environmental impacts, and economic evaluation (except for calculations of profit) are the same in case 1 and 2 (first solution), as well as in case 3 and 4 (second solution). The table below summarizes main features of the power plant in term of technology and economy.

Table 19: Main technical-economic parameters of Ut Hien power plant in 4 cases

Feature	Unit	Case 1 and 2	Case 3 and 4
Available amount of husk for electricity generation	tonne/year	20000	6030
Size of the power plant	kW	1860	670
Operating hours	h/year	6000	5000
Technology		Combustion, fluidized bed/grate type, steam turbine	Combustion, fluidized bed/grate type, back-pressure steam turbine
Heat-to-power ratio		4	13
Investment cost	million USD	8.95	3.22
- Equipment cost	million USD	6.88	2.48
- Other costs of investment	million USD	1.25	0.45
- Expenses	million USD	0.81	0.29
O&M cost yearly	million USD	0.26	0.10
- Labor cost	million USD	0.06	0.02
- Maintenance cost	million USD	0.21	0.07

5.2.1. Technical solution

Under circumstances when all rice husk produced is utilized for electricity and heat generation, not only satisfy the mill's demand but also to sell spare power to the national grid (case 1 and 2), Ut Hien's power plant has a size of 1860 kW, with operating hours being 6000. Based on its size and the correlation between heat and power demand at the mill, combustion technonology with fluidized bed boiler or moving grate and steam turbine is chosen. Electricity and heat produced yearly are 11.2 GWh_e and 44.6 GWh_{th}, respectively, with heat-to-power ratio being 4.

On the other hand, when rice husk-based power and heat generated only to supply for the mill, there is remaining raw husk to put into market (Case 3 and 4). In these cases, size of the plant is significantly smaller, nearly 3 times in comparison to the first solution, namely 670 kW. With this size, it is possible to apply gasification for the power plant. Howerver, due to high heat-to-power ratio required for the co-generation system, namely about 13 times, the suitable technology is combustion with a furnace (fluidized bed boiler or grate type) and back-pressure steam turbine. Every year this power plant cogenerate 3.3 GWh of electricity and 43 GWh of heat, with heat-to-power ratio as high as 13 times. The spare heat which is unused by Ut Hien is utilized for its sister mills.

5.2.2. Social and environmental aspects

As a result of different sizes, the bigger power plant in case 1 and 2 obviously creates more jobs in the regions, with 12 positions compared to 5 in the second solution. Furthermore, its total positive impact in CO_2 emission reduction also roughly 3 times greater than the other plant's, being 4.74 and 1.41 thousand tonne CO_2 annually, respectively. Therefore, through the whole life time, the 1860-kW power plant reduces nearly 95 thousand tonne of CO_2, while the smaller plant only contributes to about 28 thousand tonne of carbon emission reduction. However, this reduction, in reality, is not likely acquired due to the neglect of the current use of husk for energy purposes elsewhere, and the CO_2 likely to be emitted there if husk is to be used for electricity generation, as mentioned in the system boundaries and the methodology.

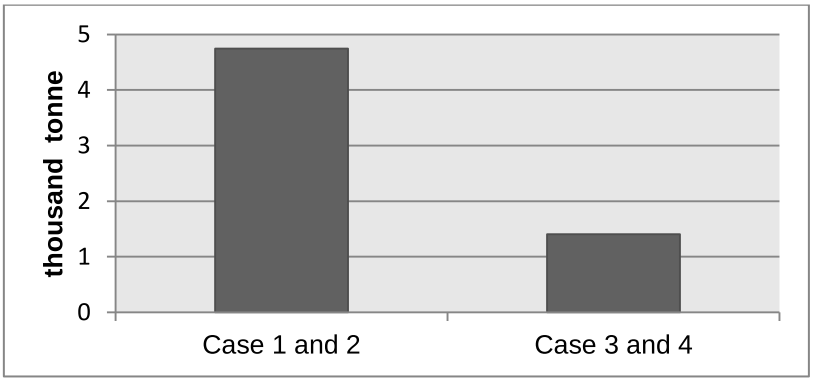


Figure 39: Total CO_2 emisson reduction through life time of Ut Hien power plant by 2 solutions

5.2.3. Economic evaluation

Since technology is combustion in both solutions with a similar cost for equipments investment cost depends totally on size of the plant. For the 1860-kW power generation system, it costs 8.95 million USD for total investment. This cost is 3.22 million USD for a similar utility at the 670-kW plant. Due to technical solution, equipment cost per unit is 3700 USD/kW, making purchase of equipments contribute to roughly 77% of total investment cost. Investment cost per unit results in 4809 USD/kW for both solutions.

Operation and maintenance is the yearly cost when the plant operates, with the first solution requiring about 0.26 million USD, more than double that of the second solution. Maintenance cost accounts for from 70% (case 3 and 4) to 81% (case 1 and 2) of the annual cost. O&M cost per each kWh is 0.023 and 0.029 USD/kWh for the first and second solution, respectively. The ratio of O&M cost/initial investment slightly fluctuates between 2.9% (case 1 and 2), and 3% (case 3 and 4).

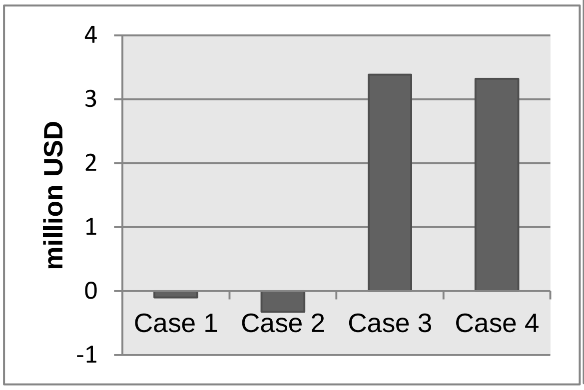
5.2.4. Profitability

The negative NPVs in case 1 and 2 indicate that this solution does not bring any profit to the project's owner. As a result the payback periods in these cases are significantly longer than the life time of the power plant, namely 3-4 times longer. On the contrary, the solution in case 3 and 4 makes the power plant profitable, proven by its positive NPVs (3.38 and 3.32 million USD, respectively). Case 3 and 4 also obtain a reasonable payback time, being more than 8 years for both cases. .

When the power plant is profitable (case 3 and 4), whether carbon credits can be sold or not has slight impact on the feasibility of the plant. As it can be seen from Figure 40, extra profit obtained from CERs sold in the market in case 3 only contributes to 1.8% of NPV, compared to case 4. Nonetheless, CERs trading plays an important role in reducing losses when it comes to the unprofitable situation (case 1 and 2). To be specific, the losses are improved by roughly 70%, from 0.33 to 0.1 million USD. It therefore shortens the payback period notably.

Table 20: NPV and payback period in the 4 cases for Ut Hien power plant

Parameter	Unit	Case 1	Case 2	Case 3	Case 4
NPV	million USD	-0.10	-0.33	3.38	3.32
Payback period	year	66.75	82.16	8.14	8.30



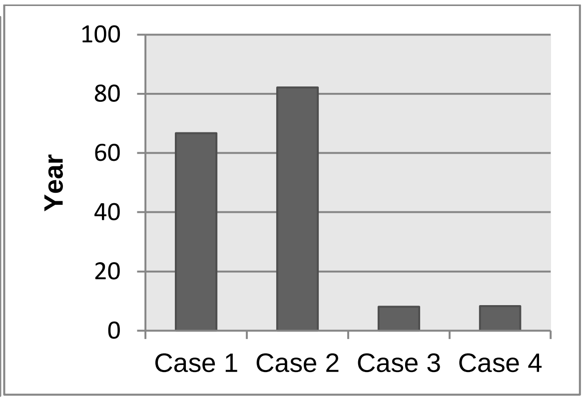


Figure 40: NPV for Ut Hien power plant (left); Figure 41: Payback period for Ut Hien power plant (right)

5.3. The 4 cases of the power plant at Vinh Binh rice mill

Similarly, there are two technical solutions for all four cases (Case 1 and 2; Case 3 and 4), leading to two arrays of results in term of social and environmental impacts and economic evaluation (except for profitability), accordingly. The table below provides main technical-economic features of Vinh Binh power plant.

Table 21: Main technical-economic parameters of Vinh Binh power plant in 4 cases

Parameter	Unit	Case 1 and 2	Case 3 and 4
Available amount of husk	tonne/year	10000	5220
Size of the power plant	kW	930	580
Operating hours	h/year	6000	5000
Technology		Gasification, gasifier, gas turbine/IC engine	Combustion, fluidized bed/grate type, back-pressure steam turbine
Heat-to-power ratio		4	8
Investment cost	million USD	6.42	2.79
- Equipment cost	million USD	5.21	2.15
- Other costs of investment	million USD	0.62	0.39
- expenses	million USD	0.58	0.25
O&M cost yearly	million USD	0.18	0.08
- Labor cost	million USD	0.03	0.02
- Maintenance cost	million USD	0.16	0.06

5.3.1. Technical solution

In the first two cases where 100% of available rice husk becomes fuel for the heat and power cogeneration system and with an operating time of 6000 hours per year, size of the plant ends up at 930 kW. Based on this figure and the ratio between electricity and heat demand, gasification using gasifier and gas turbine is chosen as the technical solution. This choice produces 5.6 GWh of power and 22.3 GWh of thermal energy every year, with excess electricity being sold to the grid.

Meanwhile, in case 3 and 4 where the rice mill only would like to feed their own demand for energy, the power plant whose size is 580 kW consumes an amount of 5220 tonnes of rice husk per annum. Although with this size, gasification seems to be attractive, yet the interrelationship between heat and power demand makes it impossible to apply this technology. Combustion using fluidized bed, back-pressure steam turbine is chosen instead. This power plant operates for 5000 hours annually to generate 2.9 GWh_e and 23 GWh_{th}. In the future when the mill expand its capacity, the spare heat is also utilized for drying systems.

5.3.2. Social and environmental aspects

The first technical solution needs to employ 6 vacancies for its 930-kW power plant, while 4 jobs are created in the second solution due to a relatively smaller plant. Regarding to environmental impact, the 930-kW plant has an ability of reducing 2.37 thousand tonne of CO_2 each year till its end of life. Comparatively, the 580-kW cogeneration utility has a CO_2 reduction emission of 1.22 thousand tonne per year, which is nearly twice as little as the other plant. By the end of its life time, the co-generation system in case 1 and 2 helps to decline nearly 47.5 thousand tonne CO_2 in total, while about 25 thousand tonne of this GHG is decreased by the operation of the other system. Yet, again, due to the mentioned neglect of CO_2 emissions, it is unlikely that this reduction will be obtained in reality.

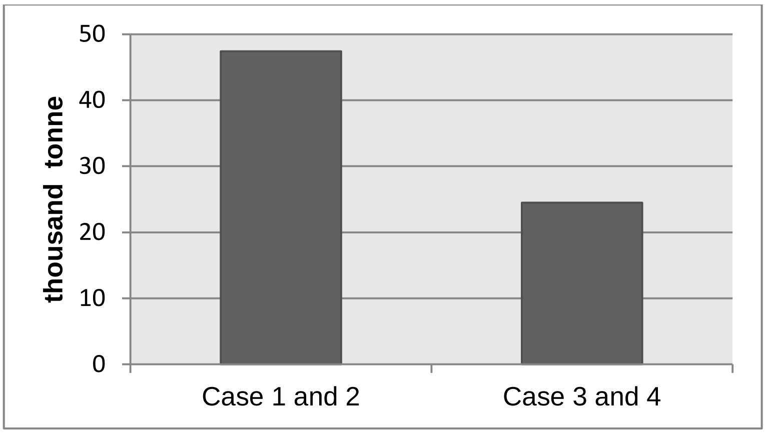


Figure 42: Total CO_2 emisson reduction through life time of Vinh Binh's power plant by 2 solutions

5.3.3. Economic evaluation

For the co-generation system which uses gasification technology, total investment cost resulted in 6.42 million USD. Equipment cost accounts for 81% of that number, as a result of the cost per unit being 5600 USD/kW. With the plant's capacity as high as 930 kW, investment cost per unit then stands at 6899 USD/kW. Yearly operation and maintenance at the power plant cost 180 thousand USD, of which maintaning activities are responsible for 89%. O&M cost per year accounts for 2.9% of the initial capital cost. Also, for this solution, O&M cost per unit is 0.033 USD/kWh.

The combustion-based power plant requires a total investment of 2.79 million USD, with purchase of equipment holding a 77% share. Based on the different technology, this 580-kW system possesses a value of 4809 USD/kW as investment cost per unit. Each year the plant needs 80 thousand USD for operating and sustaining, with 75% being taken by maintenance-related work. O&M cost is 0.029 USD for each kWh produced annually. The ratio of yearly O&M cost and the total investment is 3%.

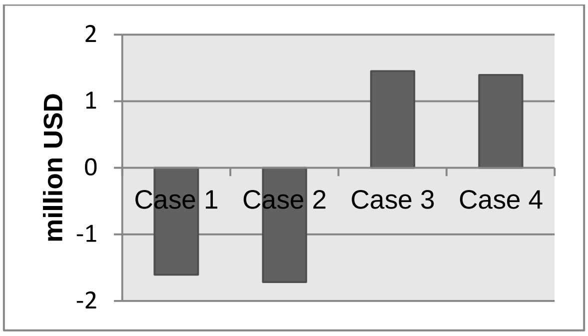
5.3.4. Profitability

Results show that technical solution in case 3 and 4 is profitatble, with their NPVs being 1.45 and 1.39 million USD respectively. This profitability leads to a payback period between 15-16 years. On the other hand, the NPVs of case 1 and 2 are negative, indicate that the solution does not create profit for the project's owner. The payback time in these cases also extremely long.

Under circumstance where the power plant is profitable (case 3 and 4), extra benefit acquired out of the possibility of selling carbon credits only contributes for approximately 4.3% of NPV, which are considered as insignificant. In the negative-NPV cases, CERs trading helps to reduce roughly 7% losses. It, however, shortens the payback time in these cases dramatically. Table 22, Figure 43 and Figure 44 below indicate these analyses.

Table 22: NPV and payback period in the 4 cases for Vinh Binh power plant

Parameter	Unit	Case 1	Case 2	Case 3	Case 4
NPV	million USD	-1.61	-1.72	1.45	1.39
Payback period	year	174.3	264.7	15.0	16.0



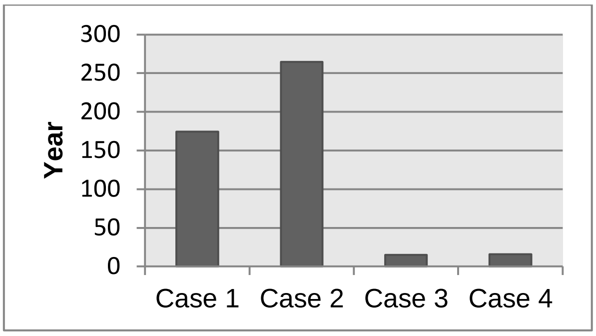


Figure 43: NPV for Vinh Binh power plant (left); Figure 44: Payback period for Vinh Binh plant (right)

5.4. Summary

The two tables below summarize all parameters in accordance to 5 aspects (technical, econimic, social, environmental, and profitable) and 4 cases (first and second solution; with and without carbon credits being sold) for each power plant at the respective rice mill.

Table 23: Summary of 4 cases for the power plant at Ut Hien

Aspect	Parameter	Unit	Case 1	Case 2	Case 3	Case 4
Technical	Available amount of husk for electricity production	tonne/year	20000	20000	6030	6030
	Size of the power plant	kW	1860	1860	670	670
	Operating hours	h/year	6000	6000	5000	5000
	Specific fuel consumption	kg husk/kWh	1.80	1.80	1.80	1.80
	Elec. Demand	GWh_e	3.30	3.30	3.30	3.30
	Heat demand	GWh_{th}	41.90	41.90	41.90	41.90
	Technology		Combustion, fluidized bed/grate type, steam turbine	Combustion, fluidized bed/grate type, steam turbine	Combustion, fluidized bed/grate type, back-pressure steam turbine	Combustion, fluidized bed/grate type, back-pressure steam turbine
	Heat-to-power ratio		4	4	13	13
	Amount of electricity	GWh_e	11.2	11.2	3.3	3.3

	generated yearly					
	Amount of heat generated yearly	GWh_{th}	44.6	44.6	43.0	43.0
Social	Number of jobs created		12	12	5	5
Environmental	CO2 emission reduction (annually)	thousand tonne CO2	4.74	4.74	1.41	1.41
	CO2 emission reduction (whole life)	thousand tonne CO2	94.86	94.86	28.11	28.11
Economic	Investment cost	million USD	8.95	8.95	3.22	3.22
	- Equipment cost	million USD	6.88	6.88	2.48	2.48
	- Other costs of investment	million USD	1.25	1.25	0.45	0.45
	- expenses	million USD	0.81	0.81	0.29	0.29
	- Investment cost per unit	USD/kW	4809	4809	4809	4809
	O&M cost yearly	million USD	0.26	0.26	0.10	0.10
	- Labor cost	million USD	0.06	0.06	0.02	0.02
	- Maintenance cost	million USD	0.21	0.21	0.07	0.07
	- O&M cost per unit	USD/kWh	0.023	0.023	0.029	0.029
	O&M/Investment	%	2.9	2.9	3.0	3.0
Profitable	NPV	million USD	-0.10	-0.33	3.38	3.32
	Payback period	year	66.75	82.16	8.14	8.30

Table 24: Summary of 4 cases for the power plant at Vinh Binh

Aspect	Parameter	Unit	Case 1	Case 2	Case 3	Case 4
Technical	Available amount of husk	tonne/year	10000	10000	5220	5220
	Size of the power plant	kW	930	930	580	580
	Operating hours	h/year	6000	6000	5000	5000
	Specific fuel consumption	kg husk/kWh	1.80	1.80	1.80	1.80
	Elec. Demand	GWh_e	2.88	2.88	2.88	2.88
	Heat demand	GWh_{th}	21.00	21.00	21.00	21.00
	Technology		Gasification, gasifier, gas	Gasification, gasifier, gas	Combustion, fluidized	Combustion, fluidized

			turbine/IC engine	turbine/IC engine	bed/grate type, back-pressure steam turbine	bed/grate type, back-pressure steam turbine
	Heat-to-power ratio		4	4	8	8
	Amount of electricity generated yearly	GWh_e	5.60	5.60	2.90	2.90
	Amount of heat generated yearly	GWh_{th}	22.30	22.30	23.00	23.00
Social	Number of jobs created		6	6	4	4
Environmental	CO2 emission reduction (annually)	thousand tonne CO_2	2.37	2.37	1.22	1.22
	CO2 emission reduction (whole life)	thousand tonne CO_2	47.43	47.43	24.48	24.48
Economic	Investment cost	million USD	6.42	6.42	2.79	2.79
	- Equipment cost	million USD	5.21	5.21	2.15	2.15
	- Other costs of investment	million USD	0.62	0.62	0.39	0.39
	- expenses	million USD	0.58	0.58	0.25	0.25
	- Investment cost per unit	USD/kW	6899	6899	4809	4809
	O&M cost	million USD	0.18	0.18	0.08	0.08
	- Labor cost	million USD	0.03	0.03	0.02	0.02
	- Maintenance cost	million USD	0.16	0.16	0.06	0.06
	- O&M cost per unit	USD/kWh	0.033	0.033	0.029	0.029
	O&M/Investment	%	2.9	2.9	3.0	3.0
Profitable	NPV	million USD	-1.61	-1.72	1.45	1.39
	Payback period	year	174.30	264.70	15.00	16.00

6. Discussion

6.1. Current status of rice husk in An Giang

Information of rice husk-related issues in An Giang is analyzed from a sample of 38 rice mills, making level of precision stand at approximately 16%. In 2012, paddy production from all regions in An Giang totalled 3.94 million tonne, of which about 0.79 million tonne is responsible by the husk. Rice production in An Giang is expected to increase in 2013 and 2014, thus the husk ought to be higher. Total paddy processed in the surveyed mills is 1.15 million tonne per year, accounted for approximately 30% of all paddy grain in the province.

Regarding to scale of business, 86.8% rice mills are in small and medium size. (Bergqvist, et al., 2008) reported that about 99% of rice mills are small scale with capacity up to 30 tonne of paddy/day in Vietnam, of which more than 70% are located in the north, with larger scale mills are mainly found in the MRD. While (Dang, et al., 2010) stated that almost all rice mills in the Mekong Delta are small- or medium-scale enterprises. Although the portion from this research is moderately smaller, it is a good reflection of previous researches, since Vietnam has been promoting bigger scale milling systems for the past years, with the Decree No.109/2010/ND-CP of November 4, 2010 on rice export business (Vietnam, 2010). The result may be an evidence for this recent trend. Also, it is therefore likely to consider the surveyed mills as a good sample for the regions.

Husk-to-paddy ratio, as mentioned in many research to range between 20%-22% (Abbas & Ansumali, 2010; Bergqvist & Wårdh, 2007; Pham, et al., 2011), is found to be roughly 19.2% from data collected in 38 rice mills in An Giang. This value is close to the identified range, yet the difference maybe due to the fact that the respondents could provide information based on numbers in their mind, rather than check the mills' book.

Generally, small mills purchase paddy grain from nearby farmers, and they usually target to local population. Due to the supply which may not be available for the whole year, it is expected that the smaller rice mills are, the shorter time they operate during the year. This expectation is proved by results from this research, with yearly operating days ranging from 246 to 360, depending on the size.

Many reports have mentioned that energy required for paddy milling and drying lays in between 30-60 kWh/tonne of paddy processed (Mathias, 2004; Tadeo, 2007 ; Lacrosse, 2013; Prasara-A & Grant, 2008). (Ekasilp, et al., 1995) reported this number is at 53 kWh/tonne of paddy, yet another study has a slightly bigger value, being 64 kWh for one tonne of paddy processed (Basappaji & Nagesha, 2013). This research results in 36 kWh for one tonne of paddy milling, excluded energy consumption for drying, therefore, is trustworthy.

Even though it was reported that in An Giang, only a small part of of rice husk production has been utilized (Piteå, 2012; Pham, et al., 2011), and that the province suffers from serous problems due to inadequate disposal of this agricultural residue, e.g., aquatic pollution and disturbed habitat for fish populations (Pham, et al., 2011), all of the rice mills surveyed claim to utilize their whole rice husk production for heating or selling. Since the husk contains monetary value, there is hardly any husk dumped into the canals and rivers. The main environmental issue created by the husk is dust, especially when it is burned to generate heat. Only 7% of the mills states that rice husk sometimes causes negative impacts on water resources. Storage area is the next issue created by the residue. However, all rice mills consider these problem to be minor, and have no significant effect.

Site observation also confirms these statements; in large rice mills where a good amount of husk used as fuel for drying system, cyclone dust collectors were installed to control the air pollution; since the rice mills locate next to a canal or river, it was not difficult to observe no husk being disposed there. Reasons for this converse finding may be firstly because of the increasingly active market for rice husk in the recent years (Santiaguel, 2013), especially for rice husk briquettes and pellets, and additionally, this research obtains information from rice mills in particular, where utilization of husk is probably better.

In contrast to (Pham, et al., 2011) that thought of cooking and brick as the main uses for rice husk, this study finds out that at rice mills, husk is mostly burned as a fuel for drying systems (more than a half), while about one fifth is compressed into briquettes which is sold with higher value, and the rest is purchased by various buyers, such as brick makers and briquette business. This dissimilarity, again, may be caused by the fact that this research focuses solely on the 38 rice mills surveyed.

Scale of business has connections to the way rice husk is dealt with; small mills prefer to sell raw husk and use little for burning, while large ones would like to utilize more husk as fuel and a modest amount of this residue for briquetting. This trend can be explained by the fact that the larger rice mills are, the more they possess their own drying systems (41% at small size and up to 80% at large size). In term of fuel for the dryers, approximately 80% of total fuel is raw husk incinerated straightly, while the other 20% taken from rice husk briquettes.

With an avarage price of 15 USD/tonne of rice husk, the result from this research is less than that in another report (Nguyen, 2011). It is reasonable since transportation cost was included in the other report, while the factor is not considered in price resulted from this study. Furthermore, the result is extremely similar to that in Thailand (Siemers, 2011), namely 15 USD/tonne. Rice husk briquettes are sold for 44.5 USD/tonne, which falls in the same range with the data reported by several sources (Customs, 2009; Kinhte24h, 2009; Phuong Nam, 2013). This economic value, however, is smaller than that in Indian market, which is identified in between 80-120 USD/tonne[4], this range is confirmed by (Ashden, 2014). The gap is due to firstly, different markets, and in addition, while the price in this research is applied at national level, it is possible that the prices listed by Indian companies are for exporting, which is usually more expensive than its local value.

Table 25: Comparion of rice husk price

Product	This research, transport excluded	Vietnam, other reports	Thailand	India
Raw husk	15.0 (5.9-28.4)	19.0	15.0	
Briquette	44.5	37.9-47.4		80.0-120.0 (price for export)

Since lack of electricity is not considered as an important problem and due to their short operating time during the year, none of small-scale rice mills express an interest in possessing a rice husk-based power system. Out of 38 studied rice mills, this kind of project attracts two medium enterprises and one large mill, which implies that owning power plants fueled by rice husk may be more suitable to bigger business.

[4] Identified by refering to prices listed by many companies who are selling rice husk briquettes in India, http://india.alibaba.com/country/products_india-rice-husk-briquette.html

6.2. Lessons learned from the unsuccessful power plant

Because profitability is the main cause of the plant's failure in electricity production, there are lessons to reduce the costs, as well as increase benefits for other to-be-built rice husk-fueled power plants, especially in the Mekong River Delta. First of all, the plants should locate so that they are able to take advantages of the convenient waterway system, in order to cut down cost for fuel transportation. It is therefore reasonable to choose suppliers whose location also suits to utilize this cheap way to transport husk.

Secondly, to avoid the unstable supply of rice husk due to compete with other buyers such as briquette makers, relatively long-term contract with sound prices with the biowaste providers need to be taken under consideration.

Rice husk ash brings another benefit which can not be ignored. It in fact carries a higher value if it is sold to other industries, such as cement or insecticides and bio fertilizers, thus new power plants should look for opportunities to connect with these factories in order to be an supplier.

Co-generation is a key factor for rice husk-based power plants. Based on an initial cost-benefit calculation, if the plant in Can Tho was operated for all year around as it claims, the benefits then would be 1.6 million USD/year, solely from steam production and utilization of rice ash. This was what had been brought profits for the plant. However, due to the fact that the power plant has been stopping for more than half a year now, lessons learned are that it is necessary to maintain a vast array of clients to consume the heat generated, and that selling steam or heat may be not totally reliable. Moreover, it also can conclude that profit obtained out of electricity sold is vital for the survival of co-generation power and heat plants fueled by rice husk.

6.3. The pre-feasibility assessment

6.3.1 Technical and economic perspectives

The assessment indicates that in term of economic evaluation, the possible rice husk-based power plants are most suitable for fulfilling their own rice mills solely, not to produce excess power for selling to the grid. By doing that, not only profitablility of the project is secured by positive NPVs, but also payback period fells within the life time of the power plants, e.g., more than 8 years at Ut Hien, and between 15-16 years at Vinh Binh.

In term of technology, despite the fact that CHP based on gas-fired ICEs (scheme 1) may have some advantages to be applied in the 670-kW power plant at Ut Hien, as well as both the 930-kW and 580-kW systems at Vinh Binh, i.e., low investment cost and simple operation, and that this technology is usually used for applications in light manufaturing, hotels, hospitals, large urban building and agriculture (IEA, 2010), its operation requires tar removing process because the dust/tar will accumulate on heat exchange surfaces. More importantly, its H:P ratio is likely too low (between 1.1 and 2.5, see table 4) to be able to fulfill the heat demand of the rice mills.

Therefore, combustion with a furnace (fluidized bed or grate type) and back-pressure steam turbine makes the best technical solution for both power plants, despite their difference in size. Back-pressure steam turbine is choosen mainly due to its high H:P ratio. To be specific, Ut Hien's co-generation system is expected to have 670 kW capacity which consumes 6030 tonne of rice husk per year and produces 3.3 GWh_e and 43 GWh_{th} every year. This power plant requires 3.22 million USD for total investment, and an annual cost of 100 thousand USD for operation and mainetance. Meanwhile, Vinh Binh's power plant is supposed to consume 5220 tonne of rice husk per year for its 580-kW cogeneration system. Each year the plant generates 2.9 GWh_e and 23 GWh_{th}. In this project, initial capital cost needed is 2.79 million USD, with O&M activities asking for 80 thousand USD per year.

According to (IRENA, 2012), fixed O&M costs tycally account for 2% of installed costs per year to 7% for most biomass technologies, in this study the ratio falls right in this range, namely 3% for both power plants.

Comparion between the profitable cases where carbon credits can be sold and without it shows that carbon trading makes a slight difference regarding to profitability. In particular, CERs sold contribute to a share of 1.8% of NPV at Ut Hien's power plant, and similarly, 4.3% at Vinh Binh's. However, the results depend heavily on CER price, which is assumed to stay the same as it happens now. The assumption used in this research is due to the price's strong variation with a downward trend through the past 4 years. Yet if it picks up a pace to grow in the future (till 2034), selling carbon credit will probably have bigger impacts. In addition, CERs trading may have a more important role in reducing losses in the unprofitable situations.

6.3.2. Social and environmental perspectives

Although the choices mentioned in the previous section are most preferable in regard to profitability, it is the other solutions which contribute the most for society and environment.

When all rice husk produced at the mills become input for their own power plant, more jobs are created for local and non-local individuals, namely 12 and 6 positions - compared to 5 and 4 vacancies in the other solutions at Ut Hien and Vinh Binh, respectively. It is also possible that extra electricity generated can supply for local population, therefore taking part in municipal development.

Larger power plants lead to bigger impacts on carbon reduction. For the power plant at Ut Hien rice mill, CO_2 emission by the first solution reduces in total about 95 thousand tonne, equals to CO_2 emission from 46.2 thousand tonne of coal burned or an amount of carbon sequestered by more than 2.4 million tree seedlings grown for 10 years. This reduction is more 337% than those achivements in the more profitable solution.

If the first solution is applied at Vinh Binh's power plant, it helps to decline an amount of nearly 47.5 thousand tonne of CO_2, equals to CO_2 emission from burning 23.1 thousand tonne of coal or carbon sequesterd by about 1.2 million tree seedlings grown for a decade, which is 194% higher than the gainings from the alternatives with better NPV. However, as stated in the assessment, if the system boundary regarding to carbon emission is expanded to the other buyers of rice husk, these reductions are unlikely to be obtained.

6.4. Possibility of competition for rice husk in An Giang

The existence of the 20-plant project was confirmed by the representative of EVN HCMC who provided feedback on the questionnaire. If the plant which is supposed to be constructed in An Giang has the same size as the first one in Hau Giang, it will need an amount of 250 tonne rice husk per day, or 90000 tonne yearly, with it operating for 360 day/year. In An Giang, available rice husk produced each year is 800 thousand tonne, and if other rice mills use this argo-residue with the same pattern as the surveyed ones in this study, 21% of the total production, namely 168000 tonne will be sold as raw material or fuel. Compared this amount with the fuel demand at the assumed 10-MW power plant, it is possible that competition for rice husk will happen if market for products made from this residue, such as briquettes, continue bustling, or start being active in case of husk pellets.

The question is that the competitive situation, if exists, will influence the studied power plants in this research or not. Within the payback period, it is reasonable to state that it will hardly affect the mill-owned power plants. Later, it will depend mainly on two factors: price of rice husk (and other products based on it, such as briquettes and pellets), and price of electricity purchased. As long as profit out of the co-generation systems is competitive with or betther than it from selling rice husk, the mills will probably maintain their plants.

7. Conclusion

The sample of 38 rice mills in An Giang shows a vast array of rice husk-related issues in the province. The analyses based on data obtained indicate that the current status of rice husk in An Giang reflects the changes (in utilization of the husk, market, policy, etc.) in recent years. Rice husk has economic values by being sold as raw material or in forms of briquettes, and thus it is not wasted or dumped to rivers and canals. It is also the fuel for drying systems at the mills. With only medium and large rice mills express their interest in mill-owned power plant based on rice husk, it is possible that this kind of project is more suitable to bigger scale business.

Low profit is the main cause of the unsuccessful rice husk-based power plant operated in Can Tho province. Thus reducing costs, such as take advantages of the cheap and convenient waterway transport system, as well as increasing benefit, for example selling rice ash for clients with better value, need to be take into consideration. Contracts with the husk suppliers should be used to maintain a stable price for the fuel. Futhermore, co-generation of heat/steam and power is a key factor for rice husk-based power plants.

In term of economic evaluation, the most profitable solution is that power plants are built and operated only to sastify the energy demand of their own rice mill. This option also reduces risk with a payback period within the life time of the project. Despite of the difference in size, combustion with fluidized bed or grate type and back-pressure steam turbine is most suitable for both studied power plants.

If social and environemtal perspectives are the focus, the choices then should be that all rice husk is utilized for power generation, with extra electricity being sold. These larger plants create more positive impacts on global warming mitigation by reducing CO_2 emission, and on society by offering more job vacancies. Yet, the reduction of carbon emission is a subject to be evaluated in a larger system boundary.

Carbon credits contribute a minor part in term of profitability. Yet if carbon price grows in the future, it will probably have bigger impacts. The existence of the 20-plant project may cause competition for rice husk in An Giang, yet is is unlikely to strongly affect the studied power plants.

Due to the fluctuations in future prices, futher research may be carried out regarding to sensitivity analysis for several parameters applied in this study. It will reduce uncertainties created by the assumptions.

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Annex

I. Questionnaires (translations)

I.1. Questionnaire for Rice Mills

Date:
Interviewer:
1. Name of the mill: ....
2. Address: ....
3. Telefone/Mobile phone: ....
4. Total area (m^2)
4.1 Working aree ($m)^2$
4.2 Storage area ($m)^2$
Area for rice husk:......................; Area for paddy, ……………
5. Type of business: ☐ Government-owned ; ☐ Private ; ☐Joint Venture
6. Capacity of paddy processed (tonne/day or tonne/year): ……
7. Number of operating days per year (day/year)
8. Material(s), product(s) and by-product(s):

Name	Unit	Quantity
1. Brown rice	tonne/year	
2. Paddy grain	tonne/year	
3. Rice husk	tonne/year	
4. Others (details)	tonne/year	

9. What issues does rice husk cause to the rice mill and how serious are they?

Issue (Yes/No)	Magnitude (Minor/Medium/Serious)	Notes
☐ Requirement for storage area		
☐ Environmental issues, such as		
☐ dust		
☐ smell		
☐ solid waste		
☐ water resource pollution		
☐ others		
☐ Others....		

10. How do you deal with the rice husk produced?

Handling method	% or tonne/year	Cost of treatment of revenues (VND/tonne)	Notes
☐ Briquette making			
☐ Burn raw husk			
☐ For heating the drying system			
☐ For other purposes:.....			
☐ Cooking			
☐ Stored for later uses			

☐ Sell (to whom?)
  ☐ Drying
  ☐ Brick kiln making
  ☐ Others:....
☐ Give it for free (to whom?)

☐ Dumped to rivers/canals

☐ Others

11. How do you deal with rice ash?
☐ Dumped it into rivers/canals ☐ Sell it (to whom?)..... ☐ Give it for farmers
☐ Others....
12. Electricity consumption (kWh/year)
13. Cost of electricity (VND/month)
14. Is the electricity taken from the national grid or other soures?
15. How much water does your mill use for operation? (m3/month), cost (VND/month)
16. How much energy consumption in your rice mill? (Quantity and/or cost/month)
☐ Diesel oil (DO) ☐ Fuel oil (FO) ☐ Petroleum ☐ Rice husk briquettes
☐ Rice husk pellets ☐ Coal ☐ Charcoal ☐ Firewood ☐ Others
17. Do you possess drying system(s)? How do you dry your paddy grain? Where is the heat from?
18. How do you transport paddy grain to your mill? Estimated distance from the suppliers to your mill? Cost for transportation?
☐ Roadways ☐ Waterways ☐ Combination of both ☐ Others
19. How do you transport rice from your mill? Estimated distance from the suppliers to your mill? Cost for transportation?
☐ Roadways ☐ Waterways ☐ Combination of both ☐ Others
20. How do you transport the rice husk from the mill? Estimated distance from your mill to the buyer(s)? Cost for transportation?
☐ Roadways ☐ Waterways ☐ Combination of both ☐ Others
21. Does you mills lack electricity? When? For how long? How are you dealing with the unsufficient supply of electricity?
22. Are you interested in possessing your own rice husk-based power system?
If yes:
What do you want to use it for? To sastify your mill's demand or to sell extra electricity to the gird? How many hour do you think the power plant will need to operate? (hour/year)

I.2. Questionnaire for the unsuccessful rice husk-based power plants

Time:
Location:
Interviewee:
Interviewee's position:
1. Name of the power plant: ....
2. Address: ....
3. Tel: ....
4. Email:
4. Features of the power plant:
4.1 Designed capacity:………….MW
4.2 Real capacity:…………..MW

4.3 When did the plant start operating:……………….
4.4 Operating days per year:
5. Does the power plant co-generate heat and power?
5. Which technology is applied for power and/or heat generation?
☐ Gasification ☐ Combustion ☐ Others...
6. Can you provide more information on the technical charateristics?
7. Which type of fuel is used for the power plant and its quantity (tonne/year or tonne/day)?
☐ Rice husk ☐ Diesel oil ☐ Coal ☐ Others
8. What is the cost for rice husk and other fuels?
9. How stable are these fuels (price, availibility, etc.)?
10. Do you meet any competition for buying these fuels? With whom?
10. How are you dealing with rice husk ash?
☐ If it is sold, then to whom? Price? ☐ Give it for free. To whom? ☐ Others
11. How do you treat wastewater? Do you have a wastewater treatment? Treatment of the wastewater is simple or complicated?
13. Who are the buyers of electricity generated from the power plant?
☐ ENV ☐ Others....
14. Who are the buyers of heat generated from the power plant?
15. What is the price of electricity and heat sold?
16. Where do you purchase rice husk? How do you transport the husk to your plant? Cost of transportation?
14. Do you meet any technical barriers while operating the plant? What are they?
☐ During the power generation process.... ☐ Wastewater treatment...
☐ Other technical problems...
15. Do you meet any difficulties in human resources, lack of skilled workers for example?
16. Do you meet any economic issues while operating the plant? What are they?
18. In your opinion, what is the reason why your plant is unsuccessful in generating power? Mark the causes below according to its magnitude from 0 to 5 (insignificant to extreme significant)
☐ High cost for rice husk ☐ High cost for transportation of rice husk
☐ Unstable price of rice husk/Competition in use ☐ Low level of electricity sold
☐ Technical issues ☐ Lack of skilled workers ☐ Low profit ☐ No profit
☐ Others..
19. In your opinion, what will help rice husk-based power plants become successful? What are the key factors?
20. How important do you think of co-generation in rice husk-based power plants?

I.3. Questionnaire for interviewing at Vietnam Electricity (EVN)

Time:
Location:
Interviewee:
Interviewee's position:
Based on your company's information:
1. How many rice husk-based power plants are operating at the moment?
2. How many rice husk-based power plants are constructing at the moment?
3. How many rice husk-based power plants are under pre-feasibility study at the moment?
4. How many rice husk-based power plants are planned at the moment?
5. What is EVN's opinion on rice husk-based power plants? Why?
☐ Should develop. Because.... ☐ Should not develop. Because....
6. Does EVN possess any rice husk-based power plants at the moment?

7. Does EVN intend to build any rice husk-based power plants?
8. Does EVN purchase electricity generated from rice husk-based power plants? At which price?
9. Recently, there has been information of a project to build 20 thermal power plants fueled by rice husk in Vietnam. The first one was expected to begin in late December 2013 in Hau Giang province with a total investment of approximately 31 million USD. According to the project, the plant has 10 MW capacity and will consume 250 tonne of husk each day. Waste from the plant will be utilized for cement production and insulation materials. The other power plants of the same kind are planned to erect in many locations in Vietnam, the Mekong Delta in particular will have 5 plants locating in the provinces of An Giang, Kien Giang, Hau Giang, Dong Thap, and Can Tho with a total capacity of 200 MW.
- Do you know about the project? Is it true?
- What do you think about the feasibility of the project?
- Can you provide more information of features (technical, econimic, etc.) of the plant in Hau Giang
- Can you provide more information of the project's owner?
- Do you have contacts to the project? Can you provide them?

I.4. Questionnaires for interviewing at the Institute of Energy, Vietnam

Date:
Location:
Interviewee:
Interviewee's position:
1. From your knowledge, how many rice husk-based power plant is available now? How many are planned to be built? Are they succesful in term of power and/or heat generation?
2. Can you provide detailed information about them?
3. Is rice husk considered as a promising energy supply? Why?
4. What difficulties do the available rice husk-based power plants meet?
5. Is there any policy which supports biomass energy in general, and rice husk in particular?
6. Recently, there has been information of a project to build 20 thermal power plants fueled by rice husk in Vietnam. The first one was expected to begin in late December 2013 in Hau Giang province with a total investment of approximately 31 million USD. According to the project, the plant has 10 MW capacity and will consume 250 tonne of husk each day. Waste from the plant will be utilized for cement production and insulation materials. The other power plants of the same kind are planned to erect in many locations in Vietnam, the Mekong Delta in particular will have 5 plants locating in the provinces of An Giang, Kien Giang, Hau Giang, Dong Thap, and Can Tho with a total capacity of 200 MW.
- Do you know about the project? Is it true?
- What do you think about the feasibility of the project?
- Can you provide more information of features (technical, econimic, etc.) of the plant in Hau Giang
- Can you provide more information of the project's owner?
- Do you have contacts to the project? Can you provide them?

I.5. Questionnaire for interviewing the responsible authority for rice husk-based power generation project in An Giang

Time:
Location:
Interviewee:
Interviewee's position:

1. Can you provide information of characteristics of rice husk in An Giang, such as husk-to-paddy ratio, moisture content, ash content, and heating value?
2. How many rice mills are there at the moment?
3. How many at small size? Medium size? Large size? How do you distinguise them? Their capacities of paddy processed (tonne/year)?
4. From your knowledge, how is rice husk normally dealt with at rice mills? Do you have figures of quantities for each type of use of rice husk?
5. If rice husk is sold, then to whom?
6. If rice husk is sold, what is its economic value (VND/tonne)?
☐ Raw husk? ☐ Rice husk briquettes? ☐ Rice husk pellets? ☐ Others?
7. How is rice husk often transported? Cost of transportation?
☐ Roadways ☐ Waterways ☐ Railways ☐ Others
8. What are the purposes of constructing rice husk-based power plants in An Giang?
9. Recently, there has been information of a project to build 20 thermal power plants fueled by rice husk in Vietnam. The first one was expected to begin in late December 2013 in Hau Giang province with a total investment of approximately 31 million USD. According to the project, the plant has 10 MW capacity and will consume 250 tonne of husk each day. Waste from the plant will be utilized for cement production and insulation materials. The other power plants of the same kind are planned to erect in many locations in Vietnam, the Mekong Delta in particular will have 5 plants locating in the provinces of An Giang, Kien Giang, Hau Giang, Dong Thap, and Can Tho with a total capacity of 200 MW.
- Do you know about the project?
- According to this project, there will be one 10-MW power plant in An Giang. Do you think it is possible?
- If this 10-MW power plant exists, how will it affect other power plants fueled by rice husk in An Giang, according to the current project between An Giang and Sweden?
- Do you have contacts to the 20-plant project? Can you provide them?

I.6. Questionnaire for potential rice mills

Time:
Location:
Interviewee:
The mills'name:
Address:
Tel:
Email:
1. Total area (m^2)
Working aree (m^2)
Storage area (m^2) Area for rice husk:......................; Area for paddy, ……………
2. Type of business: ☐ Government-owned ; ☐ Private ; ☐Joint Venture
3. Capacity of paddy processed (tonne/day or tonne/year): ……
4. Number of operating days per year (day/year)
5. Material(s), product(s) and by-product(s):

Name	Unit	Quantity
1. Brown rice	tonne/year	
2. Paddy grain	tonne/year	
3. Rice husk	tonne/year	
4. Others (details)	tonne/year	

6. What issues does rice husk cause to the rice mill and how serious are they?

Issue (Yes/No)	Magnitude (Minor/Medium/Serious)	Notes
☐ Requirement for storage area ☐ Environmental issues, such as ☐ dust ☐ smell ☐ solid waste ☐ water resource pollution ☐ others ☐ Others....		

7. How do you deal with the rice husk produced?

Handling method	% or tonne/year	Cost of treatment of revenues (VND/tonne)	Notes
☐ Briquette making			
☐ Burn raw husk ☐ For heating the drying system ☐ For other purposes:.....			
☐ Cooking			
☐ Stored for later uses			
☐ Sell (to whom?) ☐ Drying ☐ Brick kiln making ☐ Others:....			
☐ Give it for free (to whom?)			
☐ Dumped to rivers/canals			
☐ Others			

8. How do you deal with rice ash?
☐ Dumped it into rivers/canals ☐ Sell it (to whom?)..... ☐ Give it for farmers
☐ Others....
9. Electricity consumption (kWh/year)
10. Cost of electricity (VND/month)
11. Is the electricity taken from the national grid or other soures?
Detailed information of the mill's operation:

Process (if any)	Technology applied	Capacity (kWh/hour or kWh/month or kWh/year)	Electricity consumption (kWh/hour or kWh/month or kWh/year)	Note
Drying				

Milling
Whitening and/or polishing
Briquetting
Pelleting
Other

12. Do you possess drying system(s)? How do you dry your paddy grain? Where is the heat from?
13. How do you transport paddy grain to your mill? Estimated distance from the suppliers to your mill? Cost for transportation?
☐ Roadways ☐ Waterways ☐ Combination of both ☐ Others
14. How do you transport rice from your mill? Estimated distance from the suppliers to your mill? Cost for transportation?
☐ Roadways ☐ Waterways ☐ Combination of both ☐ Others
15. How do you transport the rice husk from the mill? Estimated distance from your mill to the buyer(s)? Cost for transportation?
☐ Roadways ☐ Waterways ☐ Combination of both ☐ Others
16. Does you mills lack electricity? When? For how long? How are you dealing with the unsufficient supply of electricity?
17. What do you plan to do with power generated from your own rice husk-based power plant?
☐ Fulfill the mill's demand ☐ Sell to EVN ☐ Sell to other buyers
How many hour do you think the power plant will need to operate? (hour/year)

II. Decree No. 109/2010/ND-CP of November 4, 2010, on rice export business

Chapter II, Article 4. Rice export business conditions

1. To export rice, a trader must fully satisfy the following conditions: a/ Being established and registering business under law. b/ Having at least 1 (one) warehouse which can store at least 5,000 (five thousand) tons of paddies and meets general regulations promulgated by the Ministry of Agriculture and Rural Development.

c/ Having at least 1 (one) rice mill with an hourly capacity of at least 10 tons of paddies which meets general regulations promulgated by the Ministry of Agriculture and Rural Development.

2. The rice warehouse and mill mentioned in this Article must be owned by the trader and located in a province or centrally run city which has export commodity rice or an international seaport with rice export activities at the time the trader applies for a certificate.

Source: http://lawfirm.vn/?a=doc&id=717