Journal of Sustainable Energy & Environment 1 (2010) 65-70

# Greenhouse Gas Balance for Electricity Production from Biomass Resources in Thailand

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**Abstract:** The two major biomass resources being used for power production in Thailand are bagasse, a byproduct of sugar production, and rice husk, which remains after milling rice. Larger resources are still reportedly unused in the two agricultural sectors sugar and rice, which are the field-based commodities sugar cane trash and leaves and rice straw. An in-depth analysis was performed on the energetic use of bagasse in the sugar industry. Considering the present utilization pattern and efficiencies both in the power production and in the sugar milling process, it was found that there is still a large potential available for excess power production from bagasse in sugar mills. Rice husk has widely been used leading to local shortages in supply and increasing costs of the resource. The field residues are mainly unused for power production probably because of uncertainty in logistics and prices. For all present and possible biomass power routes LCA (Life-cycle Analysis) was conducted to establish the respective figures on energy balance and greenhouse gas (GHG) emissions. These figures were compared to the conventional power sector in Thailand to establish the net savings effect of the utilization patterns. The best results were compiled for bagasse since other resources need more fossil energy input into preparation and transport. Finally, the production costs per unit of electricity were calculated to demonstrate the viability, under the present condition in Thailand, for the power export to the national grid. The options in the rice sector lead to unfavorable economic results whereas in the sugar sector good returns are possible.

**Keywords:** Biomass Resources, Power Production, Energy Balance, Greenhouse Gas Balance, Sustainability.

## 1. Introduction

Biomass resources or more precisely solid biomass fuels are the major renewable energy source in Thailand being already used to a certain extent and also being planned for further expansion for power and heat production. Policy planning for the different planning periods foresees major contribution by biomass resources in the power and heat sector. More recently, the overall target was set to 20.4% renewable energy by 2022 [1] and before the target had been set to 8% to be reached in 2011 [2]. Different studies are available on the overall potential, the technical and the economical backgrounds [3,4]. However, up to now, there are still some uncertainties on the feasible potential and on the actual effects of the different options. In a recent research study [5] some biomass electricity production options were investigated and data established for power production details, for LCA and for costs. The options chosen reflect the main sources for biomass power potential in Thailand such as:

a) present and future use of bagasse in both cogeneration and independent power plants,
b) use of field rests from sugar cane production in co-combustion,
c) use of rice husk in biomass power plants, and
d) possible use of rice straw in biomass power plants.

The results could be used for a further discussion on targets and on possible adjustments in the energy policy to ensure that projected targets can be met in the foreseen time periods.

## 2. Experimental

One major tool used in the analysis consists of a data bank application for emission calculation. This program was developed in Germany and is in widespread use internationally. In this global emission calculation program (GEMIS), products and processes are defined and can be linked to process chains [6]. Once established, different calculations and results are available, such as energy balances, greenhouse gas emissions, other types of emissions and resource use. Basic inputs would be data from LCA along the production chain for the different commodities. For this study, the necessary input data were taken from available resources, reports and publications and were verified, completed and given more details.

Allocations for all biomass resources were not made for the upstream process for agriculture, transport and processing. The only commercial products were sugar and rice. All inputs, therefore, have to be allocated to the main products, sugar and rice. The byproducts, which are inevitable associated with the main production, are "emission-free" at the source of generation. The LCA begins for bagasse and rice husks at the sugar mill after crushing and at the rice mill after milling, respectively. For the field residues, the LCA starts at the field situation, where the resources are scattered with the conditions after the harvesting.

For the technical description of power production in sugar mills, there was also the need to analyze and establish data reflecting the actual situation. Production figures from the sugar sector [7], plus additional questionnaires and site visits were used to establish key indicators such as export power potential (expressed as units per ton of cane production, kWh/TC) and electrical efficiency, taking into account the cogeneration mode and the state-of-the-art technology.

For financial analysis, standard spreadsheet models were adopted to the situation in Thailand with average input data configurations and specific plant data from real plants respectively from available reports (as in CDM-related documents).

## 3. Results and Discussion

### 3.1 Energy analysis of sugar mills

Bagasse is traditionally used in sugar mills as the main fuel for the energy demand, both for steam and electricity, in sugar processing. The operation can be described as low-pressure steam production, use of steam for milling and sugar cooking, and partially converting steam into electricity in the backpressure mode. The target was to utilize the bagasse fully throughout the season to avoid any surplus or waste problems for the mill. This resulted in quite low overall conversion efficiencies. Theoretically, there should be a substantial export potential for power available, if modern conversion and process technology is used. To indicate the potential, it is assumed that 1.0 TC (ton of cane) delivers

0.28 tonnes of bagasse [8] with a NCV (net calorific value) of 7.2 MJ/kg [8] followed by conversion of bagasse with 25% electrical efficiency (high) to deliver 140 kWh of electricity. The demand for electricity in a high efficient mill is approximately 20 kWh/TC [9]; therefore, the theoretical maximum surplus is 120 kWh/TC, assuming the heat demand could be supplied by waste heat and/or extracted steam.

The actual situation is rather complex as a multitude of factors influence the final output. In order to simplify and to use descriptive and comparable figures, a model was set up for the description of the situation. In analyzing the data, it can be seen that certain groups of sugar mills can be distinguished, each of which have certain characteristics. The groups are summarized in Table 1, giving their share of the total sugar production in Thailand, their export potential and the average electricity generation efficiency. A spreadsheet programme was set up containing information for each individual sugar mill (from available company information, through questionnaires, site visits and based on some realistic assumptions in cases where the information was not complete) especially total cane production, installed electrical capacity and produced or exported electricity generation, respectively. Finally, individual figures for the specific exported electricity in kWh per ton of cane production for different years were calculated. These results are summarized below as a model description or a technology learning curve.

Accordingly, roughly 20% of the sugar milling capacity in Thailand does not export power to the grid (in Table 1). Another 35% of production with an average of 5% electrical efficiency would export an average of 5 kWh/TC. By increasing the system pressure from 20 bar to 40 bar, an efficiency gain of up to 7% overall is possible and which also enables higher exports of 12.5 kWh/TC. This group also represents some 30% of production. Higher efficiencies need high pressure systems and a shift from backpressure turbines to condensing or condensing-extracting turbines. Only recently these power plants have been established either still on-site at the sugar mill or as independent power producers attached to a sugar mill complex (mainly as CDM projects in Thailand).

The combined modeled results for Thailand are given in Figure 1. The horizontal axis represents the share of the total cane production and the vertical axis the resulting export power in kWh/TC. The light grey columns describe the actual situation as given in Table 1. The high export potential group with 70 kWh/TC represents 10% of production. In this group, which combines some 75 MW installed capacity, a total of 490 GWh electricity is produced per year running at a full load capacity of 6,500 hours (as the power plant is independent from the sugar milling process and accumulates surplus bagasse for continuous operation). The next group of 5% production (cumulated in Figure 1) at 35 kWh/TC produces 123 GWH with 20 MW capacity and 6,000 running hours. The smaller export potential at around 12.5 kWh/TC represents the sugar sector bound power production as the full load running hours of 2,500 h are equal to the milling season in Thailand (100 days). Export capacity would be 100 MW with a production of 263 GWh. The last group with low efficiencies and no continuous export production (only 1,500 full load hours) represents 80 MW and 123 GWh of production. In summary, the model reveals a total production of some 1,000 GWh with an installed capacity (virtual installed as actual capacities differ) of 275 MW and an average full load of 3,640 h (or 41% capacity factor).

**Table 1.** Present export figures for Thai sugar mills.

| Description | Share of production | Export electricity | Efficiency |
|---|---|---|---|
| | % Ton of Cane | kWh/Ton of Cane | % |
| Mill with no export, 20 bar | 20 | 0 | 4.0 |
| Mill with limited exports, 20 bar | 35 | 5.0 | 5.0 |
| Mill with higher exports, 40 bar | 30 | 12.5 | 7.0 |
| Mill with high export, on-site, 70 bar | 5 | 35.0 | 17.5 |
| Mill with high export, off-site, 70 bar | 10 | 70.0 | 20.0 |
| Total/average | 100 | 14.25 | 7.53 |

### 3.2 Results of emission calculation for sugar sector

The total theoretical potential is represented by the full area in Figure 1 and would amount to 8,400 GWh of export electricity (calculated as 120 kWh/TC times the production of 70 Mt of cane). To achieve that, and based on 6,500 load hours, the installed capacity would be at 1,300 MW. As this figure does not seem realistic, an intermediate approach can be seen in Figure 1 (the dark-grey columns) roughly doubling the electricity production to 2,000 GWh. To achieve that objective, two main measures are necessary. Firstly, more sugar mills have to participate in the export production with slightly higher efficiencies. This might be possible with only slight changes at the respective sugar mills. Secondly, the contributions of the two highly efficient groups should be doubled. This measure would necessitate major investments in new boilers and/or new turbines to increase overall efficiencies, i.e. moving more sugar mills into high exporting ones. As a result a total of 460 MW installed capacity would produce at slightly higher load hours of an average 4,359 h. The individual contributions of the current 3 groups are displayed in detail in Figure 1.

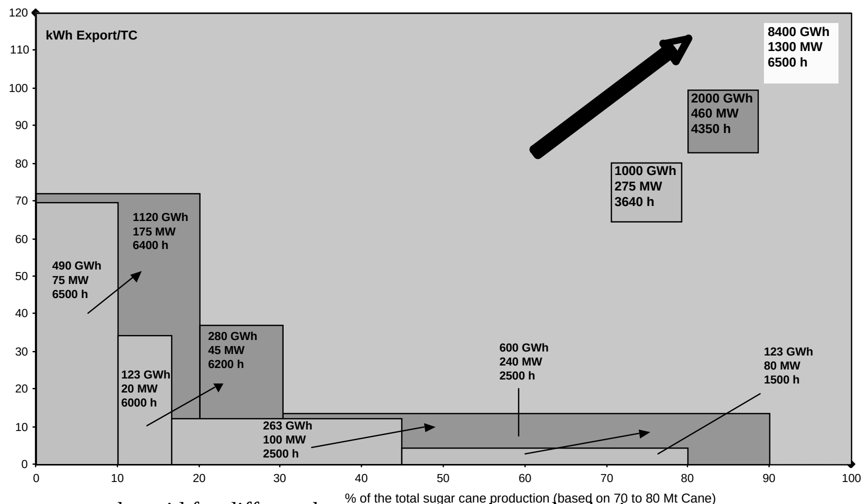


**Figure 1.** Electricity export to the grid for different bagasse cogeneration technologies.

The final energy demand on electricity is reported as 133,200 GWh [10] in the year 2007 for Thailand. The present contribution of the sugar sector therefore represents 0.75% of that demand. The near-term increase to 2,000 GWh would increase the share to 1.5% in total.

After the establishment of the technical background for electricity production from bagasse, the data can be input into the emission calculation program. Three technology groups are differentiated, characterized as the 20 bar group, the 40 bar group and the advanced 70 bar group with their respective efficiencies. Bagasse as biomass fuel is regarded as emission free at the source of the power plant (renewable resource and no allocation made for agriculture and transport since a byproduct of sugar production). The only GHG emissions that would be emitted by the combustion process are methane ($CH_4$) and nitrous oxide ($N_2O$). As no reliable data are available at this stage, the default values used by IPCC were used [11] and accordingly changed to fit into the GEMIS system. In most of the cases, bagasse is used as fuel in cogeneration mode. Thus, an allocation has to be made for the alternative steam production and use based on overall efficiency and technology status. Credits are then given to the electricity production for that amount of steam being co-generated in comparison to an isolated boiler steam operation fuelled by bagasse.

The final results are displayed in Figure 2. Basically, the GHG emissions are rather low below 40 kg of $CO_{2eq}$ per MWh electricity produced. Due to the impact of efficiency, the 20 bar technology shows higher emissions as compared to the 70 bar technology. The 70 bar option works in condensing mode (not supplying steam, but operating at higher electrical efficiency) and increases total GHG only slightly. The present mix in Thailand of bagasse based electricity has a value of some 26 kg of $CO_{2eq}$ per MWh. These figures are to be seen against the present grid emissions, which are in the range of 621 kg of $CO_{2eq}$ per MWh offering a nearly 600 kg/MWh net reduction. A further note is important for the grid emissions data. The figure of 621 kg $CO_{2eq}$/MWh is a result of another GEMIS modeling of Thailand's electricity production for the year 2006 [12]. In this approach, all major power plants with their efficiencies and fuel consumption were established and modeled into GEMIS. Fuel data were used also reflecting the specific conditions in Thailand. The presented figure, therefore, is slightly higher than the comparable data as GEMIS includes the fuel processing at the source and the transport efforts as well. Another impact is due to the different fuel properties (here taken as original fuel characteristics for Thai fuels) as compared to IPCC default values. Against the well-established use of bagasse in the sugar sector for energy, the so-called field rest has only a minor contribution. Field rests are the remains of the sugar cane plants in the field after harvest and consist of cane tops, leaves and trash. For energy utilization, these resources would need collection from the field, additional transport and further handling at the power plant. The easiest way for power generation could be co-combustion in bagasse boilers at a certain maximum rate (20% seem not to create problems). This avoids additional power plant capacities and investments. The necessary handling efforts consume fossil energy, which results in higher GHG emissions, as shown in Figure 3. The final figures range from 24 to 87 kg $CO_{2eq}$/MWh, which is still a comfortable net gain as opposed to the present electricity grid's GHG emissions. In the emission calculations, a benefit for avoiding the field burning of cane was not allocated. Nearly 50% of all cane fields are burned prior to harvesting to ease harvest operations, which in this case, is mainly manual labor. To change that tradition needs more intervention, as can be foreseen from the energy perspective only.

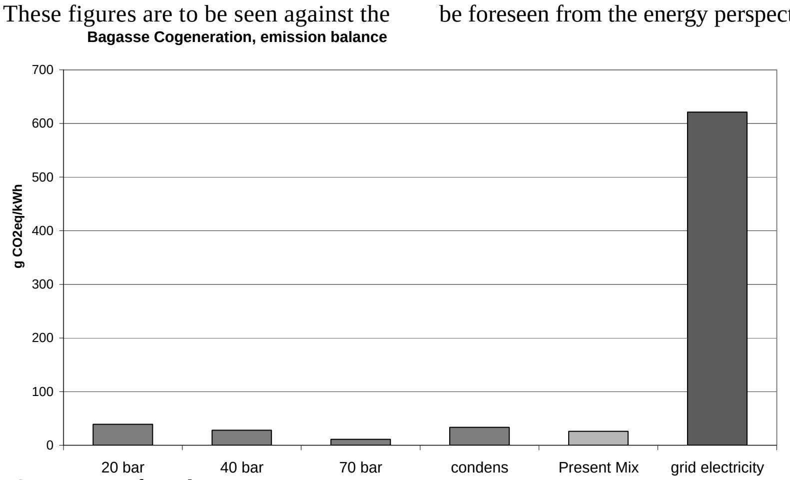


**Figure 2.** Life-cycle GHG emissions from bagasse cogeneration.

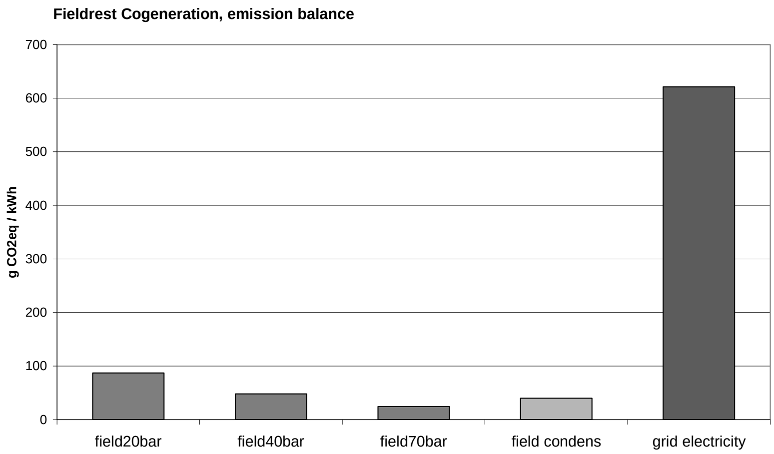


**Fig. 3.** Life-cycle GHG emissions from sugar cane field residues for power generation.

### 3.3 Results of emission calculation for rice sector

The rice sector produces two different forms of potential energy resources, which are rice husk as a byproduct of rice milling and rice straw as a resource left in the fields. The situations of these two resources are rather different and have to be analyzed separately.

In recent years, due to high fossil fuel prices and favourable conditions in the power sector, rice husks are used in power plants for electricity production and mainly for export to the national grid. In the small power producer scheme (SPP), a total of 16 power plants fully or partially uses rice husk as fuel. The estimated installed capacity based on rice husk alone is around 140 MW. Another 9 companies are registered under the very small power producer scheme (VSPP) with a total installed capacity of 50 MW [13]. These capacities can be satisfied with an amount of roughly 1.7 Mill t of rice husks, representing 28% of all available rice husks. For VSPP, another total capacity of 170 MW installed is already approved (according to the classification by EPPO) and could come into operation in the next 2 or 3 years because the licensing process is complete and construction could start for these projects. Waiting for approval are 25 MW in SPP and 100 MW in VSPP as well as planned VSPP of 100 MW [13]. The situation can be summarized as: the existing 190 MW capacity could likely increase to 360 MW and could lead to a total of 585 MW installed capacity. The last figure would virtually consume all rice husks in Thailand, which is not a realistic option as there are already traditional non-energetic and energetic uses and in addition established industrial consumers. In summary, however, all resources for rice husk would be utilised in the near future. Rice husk power plants are generally stand-alone operations with only limited demand for cogeneration or in-house consumption. As in most cases new power plants are always built with technology, which is more advanced, higher overall efficiencies can be assumed. Rice husk are transported (sometimes over long distances and using fossil-based transportation fuels) to the power plants site.

Rice straw is not used for energy purposes besides some small-scale application. The major reason is the unclear logistics and the costs of the resource for any larger scale energy production. Theoretically, rice straw also has to be collected at the field site, then compacted to make transport viable, and finally it has to be transported to a power plant. These would involve farm operation and additional machinery, which result in fossil energy demand. At the power plant rice straw needs further processing before being combusted and converted in the boiler. The resulting efficiency should be slightly lower than for rice husks. Major input figures for the two cases of rice residue utilisation are given in Table 2.

The results of the GHG emission calculation are shown in Figure 4. As expected, the fossil energy demand for the transport of rice husks and the whole logistical efforts for straw increase the total GHG emissions substantially as compared to the bagasse case, although the efficiency is higher (similar GHG emissions for $CH_4$ and $N_2O$ in combustion). Rice husk power would emit a total of 67 kg $CO_{2eq}$/MWh, whereas rice straw results in some 180 kg $CO_{2eq}$/MWh. This reduces the potential net GHG savings accordingly.

### 3.4 Impact of emissions calculation

Based on the reported production figures at present and on the stated specific emissions from the analysis, the global impact of the different biomass feedstock can be seen in Figure 5. Highest theoretical emission reductions (as t $CO_{2eq}$ per year for Thailand) are possible through the utilization of field residues from the sugar sector with more than 5 mill. tons of $CO_{2eq}$ net reductions per year. Only a small potential of this is already utilized (see Figure 5). The second highest potential, which is just below 5 mill. t of emission reduction, can be seen from rice straw but there is no use at present. The potentials for reductions through bagasse and rice husk in power plants are lower but their present contribution, which are 500,000 t of net reductions per year each, are higher.

**Table 2.** Input figures into GEMIS based LCA.

| | |
|---|---|
| Rice data [a] | |
| Productivity | 2.50 t/ha |
| Husk ratio | 0.21% |
| Straw ratio | 0.75% |
| Transportation of rice husk [a] | |
| Distance | 300 km |
| Baling for straw [a] | |
| Traktor | 60 L diesel/ha |
| Transportation of straw bale [a] | |
| Distance | 150 km |
| Efficiencies | |
| Husk power plant | 20% |
| Straw power plant | 18% |
| Lower Heating Value [b] | |
| husk | 13.27 MJ/kg |
| straw | 13.95 MJ/kg |
| Diesel | 42.72 MJ/kg |
| Diesel | 35.88 MJ/L |
| Diesel density | 0.84 kg/L |

[a] Data collected from field survey
[b] Data from GEMIS

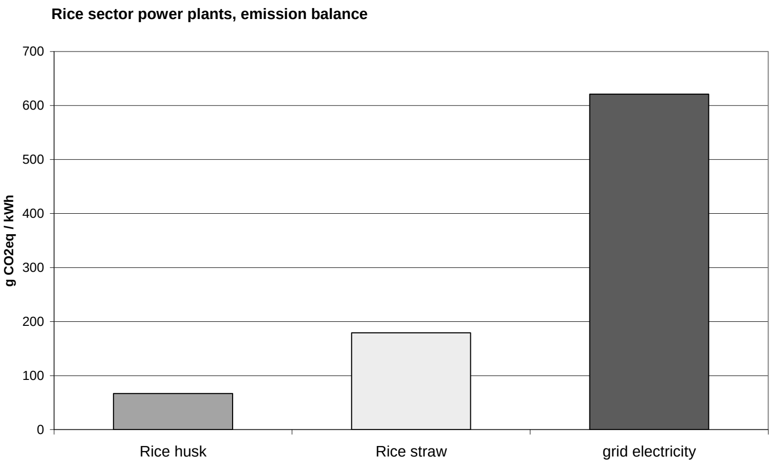


**Figure 4.** Life-cycle GHG emissions from rice husk and rice straw for power generation.

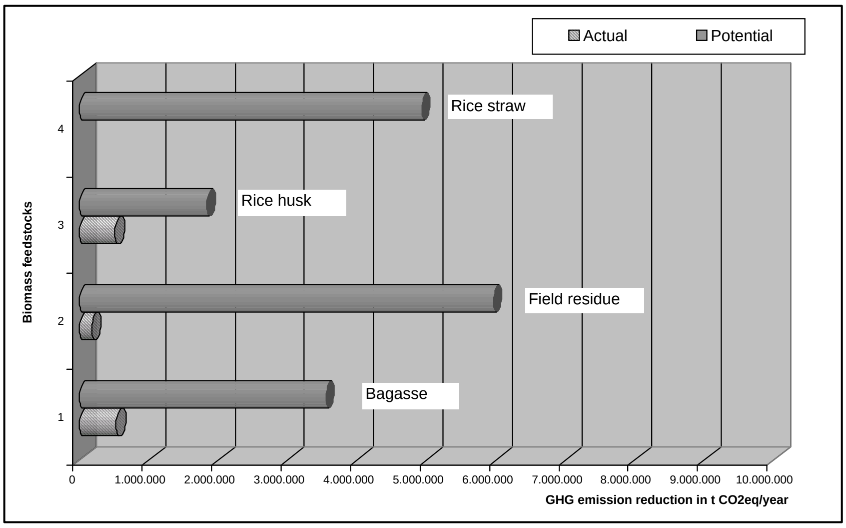


**Figure 5.** Life-cycle GHG emissions reduction potentials from various biomass feedstock used for power production.

### 3.5 Financial results for sugar and rice sector

A financial analysis was performed for some of the main configurations of different power plants. For this purpose, a spreadsheet model program was also developed and used for the financial calculations. The general data are displayed in Table 3. Basically the production costs per unit electricity are derived from the expenses-revenue balance divided by total export production. Capital costs are expressed as annual cost using the annuity concept. In a second step, the internal rate of return and the net present value are calculated based on a 20-year lifetime cash flow analysis. Some of the selected results are displayed in Table 4. Thereby the different discussed cases reflect the different groups of power plant configurations which have been discussed in the previous sections. The first base case 1 describes the situation in an existing sugar mill, where with minor investments (e.g. grid connection) and some operational changes of existing equipment, small amounts of surplus power are generated. The production costs per unit of excess electricity are quite low with 0.215 THB/kWh. For the sale of electricity, a wholesale price of 2.41 THB/kWh (the average price in 2009 as published by DEDE [14]) is assumed plus the adder component of 0.3 THB/kWh (the applicable adder for biomass based electricity feed-in [14]), which leads to high IRR values as the initial investment is low. In the financial model, fuel costs for bagasse are assumed but compensated through sales of steam. The similar setup case 2 for using field residues (valued at 700 THB/t at power plant) increases the production cost to some 1.18 THB/kWh, but is still very viable in terms of IRR. The next case 3 characterizes technical improvements and capacity increases at the power plant (e.g. boiler retrofit, turbine refurbishments) and also results in favorable production cost and financial IRR. In order to increase the export electricity a shift to condensing modes of the turbine operation is necessary. This usually would usually call for a new turbine and/or boiler refurbishments (increase to 70 bar, continuous operation). Results for case 4 are still viable and offer good returns, as well as for co-combusting field residues (case 5). A large independent power plant (case 6) shows the highest production costs as well as the highest export potential. The final IRR is on a threshold level, but may still encourage investments, although the payback time would be increased.

High fuel cost for rice husk (at 1,000 THB/t) increase production cost to 2 THB/kWh (case 9 for large 22 MW plant) and to 2.5 THB/kWh (case 7 for new VSPP plant at 9.9 MW) and reduce IRR to levels which are no longer attractive. In the case of rice straw at the same configuration, the high resource cost of 1,250 THB/t prohibit investments in any configuration as production costs are high with 2.9 and 2.5 THB/kWh already, leaving only a small 2% IRR.

**Table 3.** Assumptions for the financial analysis.

| | |
|---|---|
| Loan | 70% |
| Equity | 30% |
| Interest rate | 7% + 1.5% |
| Bank Loan | 10 years |
| Lifetime of project | 20 years |
| Bagasse | 350 Baht/ton |
| Field rest | 750 Baht/ton |
| Rice husk | 1,000 Baht/ton |
| Rice straw | 1,250 Baht/ton |
| Electricity internal | 1.8 Baht/kWh |
| Electricity VSPP | 2.41 Baht/kWh |
| Electricity SPP | 2.20 Baht/kWh |
| Adder for feed-in | 0.30 Baht/kWh |
| Steam internal | 300 Baht/MWh |
| Steam sales | 500 Baht/MWh |
| Operation and maintenance | 4% of Investment |
| Insurance | 1.5% of investment |
| Salary average | 400,000 Baht/year |
| Specific investment | According to project type |
| Electricity and steam production | According to project type |
| Efficiency | According to project type |

**Table 4.** Selected results of financial analysis.

| Description | Base case | IRR w/o tax |
|---|---|---|
| | THB/kWh | % |
| 1 Bagasse 20 bar 4 MW backpressure, 1500 h | 0.215 | 402.08% |
| 2 Field rest as co-combustion | 1.179 | 250.33% |
| 3 Bagasse 40 bar 8 MW backpressure, 2500 h | 0.735 | 55.72% |
| 4 Bagasse 70 bar 8 MW condensing, 6875 h | 1.656 | 34.06% |
| 5 Field rest as co-combustion | 1.738 | 32.11% |
| 6 New power plant 70 bar 30 MW, condensing-extracting mode, 7000 h | 1.996 | 14.83% |
| 7 Rice husk power plant 9.9 MW | 2.496 | 9.92% |
| 8 Rice straw power plant 9.9 MW fictive | 2.923 | 2.01% |
| 9 Rice husk power plant 22 MW | 2.060 | 13.13% |
| 10 Rice straw power plant 22 MW fictive | 2.459 | 2.01% |

## 4. Conclusion

According to this analysis, the best options that are still available for using bagasse in power plants are increasing efficiency at mill operation and maximizing the export potential for electricity. Bagasse also offers the highest net GHG savings per unit of power. Bigger potentials exist in the field rest segment both for cane and rice straw with total potentials in the range of 5 mill. tons of $CO_{2eq}$ per year. However, there are still technical and financial constraints to overcome. The actual contribution to net GHG savings in Thailand is leveled between bagasse and rice husk at 500,000 t of $CO_{2eq}$/year, but due to recent developments rice husk would overtake bagasse as the main contributor to GHG savings. Proposed measures for bagasse and reaching the full theoretical potential would need more time and effort.

## Acknowledgments

The author gratefully acknowledges the contribution of various colleagues from JGSEE and from the industrial sector during interviews and field trips. Most of the research work was conducted using research grants from the Thailand Research Fund, made available under the Energy Policy Project Phase 2 on behalf of the Ministry of Energy, Energy Policy and Planning Office.

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