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Energy Efficiency Improvement and Carbon Dioxide Emission Reduction in Thai Pulp and Paper Industry

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Abstract— ***Energy consumption in Thai manufacturing sector in 2009 was 23,798 ktoe and accounted for 35.7% of the final energy consumption of the country and the worth of purchased fuel and electricity in Thai pulp and paper industry accounted for over 7.7% or 1,836 ktoe of the energy consumption in manufacturing sector. The major energy consumed was coal, shared 86.0% of the energy consumption in this sector, followed by electricity and petroleum products which shared 9.4% and 4.5% respectively, natural gas and renewable energy consumption is small in pulp and paper manufacturing sector. The pulp and paper industry converts fibrous raw materials into pulp, paper, and paperboard. The processes of papermaking include raw materials preparation, pulping (chemical, semi-chemical, mechanical, or waste paper), bleaching, chemical recovery, pulp drying, and papermaking. The most significant energy consuming processes are pulping and the drying sections of papermaking. Energy efficiency improvement is essential for the reduction in energy usage, which in turn decreases the production cost, especially in times of high energy price mutability, and causes more profit. There are a variety of opportunities available at individual plants to reduce energy consumption, including a wide range of energy efficiency practices for organizational levels and energy-efficient technologies, i.e. steam generation and distribution systems, motors, pumps, air compressors, and combined heat and power system, that can be implemented at the component, process, and facility. Also provided is a discussion of the energy consumption characteristics of Thai pulp and paper industry along with a description of the major process technologies used within the industry. In addition to the specific energy consumption (SEC), the conservation supply curve (CSC) is derived in this study, base on a data from Thai pulp and paper industry. The curve shows the energy conservation potentials as function of the marginal cost of conserved energy (CCE), which can be useful for the energy efficiency improvement for other factories in Thai pulp and paper industry.***

Keywords— ***Energy efficiency, Pulp and paper Industry, Conservation Supply Curve (CSC), Specific Energy Consumption (SEC), Cost of conserved energy (CCE)***

I. Introduction

In 2009, manufacturing sector of Thailand consumed 23,798 of final energy consumption, almost one-quarter of all energy consumed that year in Thailand. Within manufacturing sector, The worth of purchased fuel and electricity in Thai pulp and paper industry accounted for over 7.7% or 1,836 ktoe of the energy consumption in manufacturing sector which is caused pulp and paper manufacturing is one of energy intensive industries. Therefore, this report reflects an in-depth analysis of pulp and paper industry.

The manufacture of paper and paperboard is an important element of a modern economy. It also is a highly capital and energy-intensive process. As such, opportunities exist for increasing energy efficiency in pulp and paper industry in Thailand.

This paper describes the energy consumption. In addition, the various technologies and measures are assessed in efficiency analysis, including estimates of costs and energy savings. Moreover, we estimate technical and cost-effective potential energy savings and the associated carbon dioxide emissions reductions from the investment in various technologies and measures.

A. *Pulp and Paper Industry Grouping*

The production structure of pulp and paper industries can be separated into 3 levels. First, upstream industry relating to pulp production which is the important raw material for producing different categories of paper in the midstream industry. Second, midstream industry includes the production of different categories of paper, for example kraft paper, printing & writing paper, tissue paper and newsprint paper, etc. Finally, downstream industry, the paper products from the midstream industry such as kraft paper and duplex board will be produced as box and packaging adding more value to the paper.[1]

B. *Process description*

The pulp and paper industry converts fibrous raw materials into pulp, paper, and paperboard. The processes involved in papermaking include raw materials preparation, pulping (chemical, semichemical, mechanical, or waste paper), bleaching, chemical recovery, pulp drying, and papermaking. A flow diagram of the processes is shown in Figure 1[6].The most significant energy consuming processes are pulping and the drying section of papermaking.

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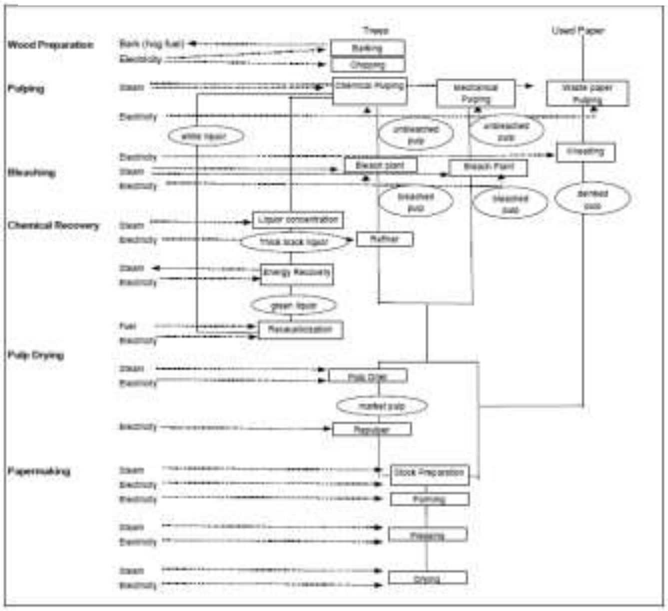

Figure 1. Schematic of the Pulp and Papermaking Process

C. *Energy use in Thai pulp and paper industry*

Pulp and paper industry are regarded as the large-scaled industry being important for country development. The worth of purchased fuel and electricity in Thai pulp and paper industry accounted for over 7.7% or 1,836 ktoe of the energy consumption in manufacturing sector. The major energy consumed was coal, shared 86.0% of the energy consumption in this sector, followed by electricity and petroleum products which shared 9.4% and 4.5% respectively, natural gas and renewable energy consumption is small in pulp and paper manufacturing sector.[2]

Table 1 Energy consumption for manufacturing sector in 2009

(Unit: ktoe)

Type of Energy	Manufacturing									
	Food and Beverages	*Textiles*	*Wood and Furniture*	*Paper*	*Chemical*	*Non-metalic*	*Basic Metal*	*Fabricated Metal*	*Others*	*Total*
Commercial Energy	1,755	863	165	1,836	2,177	6,533	1,030	1,244	1,501	17,104
Coal and Its products	121	136	-	1,579	27	5,123	83	-	424	7,493
Bituminous	111	128	-	228	6	1,461	0	-	40	1,974
Anthracite	-	-	-	-	-	9	76	-	53	138
Coke	-	-	-	-	-	-	7	-	-	7
Lignite	10	8	-	19	1	831	-	-	1	870
Briquettes,Other Coal	-	-	-	1,332	20	2,822	0	-	330	4,504
Petroleum Produvt	571	101	40	84	338	183	255	148	844	2,564
LPG	28	17	2	5	173	93	84	97	185	684
ULG 91	1	0	1	0	1	0	0	1	4	8
ULG 95	1	0	0	1	0	0	-	1	2	5
Kerosene	1	1	0	0	3	0	0	2	2	9
HSD	310	11	33	27	75	50	32	39	316	893
LSD	-	-	-	-	-	-	-	-	-	-
Fuel Oil	230	72	-	51	86	40	139	8	335	965
Natural Gas	124	46	4	-	1,000	703	209	44	182	2,308
Electricity	939	580	-	173	812	524	483	1,052	51	4,739
Renewable Energy	5,527	-	125	-	262	873	-	-	-	6,694
Fuel Wood	235	-	32	-	40	132	-	-	-	412
Agricutural Waste	1,289	-	5	-	222	723	-	-	-	2,261
Paddy Husk	1,177	-	27	-	-	18	-	-	-	1,195
Bagasse	2,826	-	-	-	-	-	-	-	-	2,826
Total	7,282	863	197	1,836	2,439	7,406	1,030	1,244	1,501	23,798

D. *Situation of Thai pulp and paper Industry*

Globally, Thailand holds the twentieth position in the pulp and paper sector and is one of the major producers of pulp, paper and paper board amongst the other developing countries in the region. Thailand has a pulp production capacity of 1.2 Mt with a utilization rate of 94% of which exports is around 0.19 Mt of pulp to other countries. The major pulp export destinations were China, South Korea, Taiwan, Indonesia and Vietnam. The change pattern in the consumption of short fibers is due to the lesser use of imported long fiber pulp from Canada, Sweden and United States of America. The estimated consumption of domestic pulp grew by 2% in line with the growth of printing and writing paper industries. It is estimated that the demand of pulp required by industries would reach around 1.4 Mt in the year 2013.[1]

Thailand has a paper and paperboard production capacity of around 4.9 Mt, whereas the actual paper and paperboard production was 4.2 Mt with a capacity utilization rate of 87%. In 2008, the consumption of paper and paperboard was 3.5 Mt, a reduction of 2% from the previous year due to the reduced consumption of specific paper grades such as newsprint paper, writing and printing paper. The actual per capita consumption of paper and paper board was 55 kg. The paper and paper boards were mainly exported to South Korea, Taiwan, and Hong Kong as well as to other South East Asian countries which are around 1.1 Mt, and marginally dropped by 5%.

In 2008, the trend shows that the increase in collection rate of recovered paper was 12% which accounts for a total volume of 2.1 Mt. Besides, the consumption of recovered paper was 3.3 Mt, an increase by 22% from the previous year. Awareness on creating friendly environment, rising cost of energy and virgin fiber prices has motivated the use of recycled pulp thus boosting the trend of recovered paper consumption. The import of recovered paper was 1.22 Mt which is higher compared to previous year by 20%. The major grades that were imported into the country were old corrugated carton (OCC), mixed waste, old newspaper respectively. The estimated recovered paper consumption is expected to grow by 3%. (Source: TPPIA, 2008)

E. *Pulp and paper industry in Thailand*

The pulp and paper sector in Thailand consists of 44 mills of which six are integrated pulp and paper mill while the others are mainly recovered paper based kraft paper, tissue paper and packaging board mill. All the paper and paper board mill are spread across the country, though most of the mills are located in the central region. The total capacity to produce pulp is around 0.25 Mt. The country's major production of hard wood pulp is mainly from eucalyptus plantations with a production capacity of 1.1 Mt whereas non wood based bleached bagasse pulp plant capacity is only 0.1 Mt.

Thai paper sector is solely dependent on recovered paper because its major paper production grades are Kraft liner, tissue and container board which is almost 70%. These recovered paper based paper mill mainly consumes the purchased power, steam and fuel oil for their process use. The integrated paper mill in the country uses biomass, such as bark from wood as a fuel, which is partially used in the production of energy and steam.

F. Major of Thai pulp manufacturers

The major pulp producers in the country are Advanced Agro Ltd and Siam Cement Group which has subsidiaries of 22 paper mill. The others are Panjapol Paper Co Ltd., Phoenix Pulp and Paper, and Environmental Pulp and Paper Co Ltd. (EPPCO). Table 2 presents the list of integrated pulp and paper mill in Thailand. These mills mainly use plantation hard wood as their raw material where as EPPCO mill uses bagasse only. The total capacity of pulp production is shared mainly by these six mills.

Table 2 Major integrated pulp and paper mills in Thailand in 2010

Name of the Company	Actual Capacity (Mt)	Raw material use /Grade produced
1.Advance Agro limited	0.560	Eucalyptus (Bleached Hardwood)
2.Phoenix Pulp and Paper	0.235	Eucalyptus, Bamboo, Acacia,(BKP)
3.Panjapol Pulp Industry	0.110	Eucalyptus (unbleached HW pulp)
4.SCG Paper	0.105	Eucalyptus, BCTMP and UBHWP
5.Siam Cellulose	0.086	Eucalyptus (Bleached Hard wood pulp)
6.Environment Pulp and Paper	0.100	Bagasse (Bleached pulp)
Total	1.196	

II. Methodology

Methodology on this paper provided a discussion of the energy efficiency technologies and measures for pulp and paper industry within the industry. In addition, the specific energy consumption (SEC), the conservation supply curve (CSC) is derived in this study, base on a data from Thai pulp and paper industry.

A. Energy Efficiency Technologies and Measures for pulp and paper industry

Table 3 provides the summary of the input data and assumptions for the scenarios. The table shows fuels, electricity, and primary energy savings per ton (t) of production, retrofit capital costs and O&M costs per ton of production, the percentage of production to which the measure can be applied nationally (by 2010), and the associated carbon dioxide emissions reductions. A detailed description of each technology and measure and estimates of associated energy savings and costs is provided as showed.[7][8]

B. The Specific Energy Consumption (SEC)

The specific energy consumption (SEC) is a ratio of energy consumption per unit of product. Moreover, SEC can reflect an efficiency of energy consumption and cost of energy for industry. The determination is on the article of what changes in manufacturing energy consumption are caused by changes in energy efficiency of the production process. For one single product x in one single process, the specific energy consumption (SEC) is defined as [5]

$$SEC = E_x \,/\, P_x \tag{1}$$

where Ex is the energy consumption of the manufacturing process and Px is the production of commodity x. In this study, the specific energy consumption (SEC) is divided into the specific heat consumption (SEC_h) and the specific electricity consumption (SEC_e). [6]

C. The Conservation Supply Curve (CSC)

The Conservation Supply Cure (CSC) used in this study in a analytical tool that captures both the engineering and economic perspectives of energy conservation. The curve shows the energy conservation potential as a function of the marginal Cost of Conserved Energy. The CCE can be calculated from Equation (2)

$$CCE = (\text{Annualized Investment} + \text{Annual Change in O\&M Costs}) / \text{Annual Energy Saving} \tag{2}$$

The Annualized Investment is calculated as Equation (3)

$$\text{Annualized Investment} = \text{Capital Cost} \times (d/(1-(1+d)^{-n})) \tag{3}$$

Where; d is the discount rate and n is the lifetime of the conservation measure. [8]

The advantage of using a conservation supply curve is that it provides a clear, easy to understand framework for summarizing a variety of complex information about energy efficiency technologies, their costs, and the potential for energy savings. The curve can avoid double counting of energy savings by accounting for interactions between measures, is independent of prices, and also provides a framework to compare the cost of efficiency with the costs of energy supply technologies.

CCEs are calculated for each measure that can be applied in the pulp and papermaking. The CCEs are plotted in ascending order to create a conservation supply curve. The width of each option or measure (plotted on the x-axis) represents the annual energy saved by that option. The height (plotted on the y-axis) shows the option's CCE. All measures that fall below the average-weighted price of energy for the pulp and papermaking industry can be defined as cost-effective.

Table 3 Energy Savings, Costs, and Carbon Dioxide Emissions Reductions for Energy-Efficient Technologies and Measures Applied to Thai Pulp and Paper Industry

Technology/Measure	Production (Mt/year)	Fuel Savings (GJ/t)	Electricity Savings (kWh/t)	Primary Energy Savings (GJ/t)	Carbon Savings (kgC/t)	Retrofit Cost of Measure (US$/t)	Annual Operating Cost Change (US$/t)
Raw Materials Preparation							
Ring style debarker	5.3	0	0.02	0.03	0.5	1.3	-0.01
Cradle debarker	5.3	0	0.03	0.05	0.8	25.8	0
Enzyme-assisted debarker	5.3	0	0.02	0.04	0.7	3.9	0
Bar-type chip screens	5.3	0.35	0	0.5	3.1	1.5	-0.7
Chip conditioners	5.3	0.21	0	0.3	1.9	N/A	-0.5
Improved screening processes	5.3	0.35	0	0.5	3.1	1.5	N/A
Belt conveyors	5.3	0	0.02	0.04	0.7	N/A	2.6
Fine-slotted wedge wire baskets	5.3	0	0.61	1.24	19.4	N/A	9.4
Pulping: Mechanical							
Refiner Improvements	0.06	0	0.81	1.63	25.6	7.7	0
Biopulping	0.06	-0.5	2.04	3.41	60.1	27	0
Pulping: Thermomechanical (TMP)							
RTS	0.06	0	1.1	2.23	35	50	N/A
LCR	0.06	0	0.51	1.04	16.3	N/A	-2.6
Thermopulping	0.06	0	1.1	2.2	35	226.7	18
Super Pressurized groundwood	0.06	0	2.67	5.4	84.7	220	N/A
Heat recovery in TMP	0.06	6.05	-0.54	7.52	37.4	21	0
Improvements in Chemi-TMP	0.06	0	1.1	2.23	35	300	N/A
Pulping: Chemical							
Continuous digesters	1.2	6.3	-0.27	8.4	48.1	196	0
Continuous digester modifications	1.2	0.97	0	1.39	8.8	1.3	0.2
Batch digester modifications	1.2	3.2	0	4.55	28.8	6.6	0.5
Chemical Recovery							
Falling film black liquor evaporation	1.3	0.8	0.001	1.14	10.1	90	0
Tampella recovery system	1.3	2.9	0	4.13	23.9	N/A	N/A
Lime kiln modifications	1.3	0.46	0	0.46	7.82	2.5	N/A
Extended Delignification and Bleaching							
Ozone bleaching	0.7	0	0.01	0.02	0.3	149.5	-2
Brownstock washing	0.7	0.01	0.05	0.11	1.5	50	-2.3
Washing presses (post-delignification)	0.7	0.39	0	0.55	3.5	17	-0.5

Table 3 Energy Savings, Costs, and Carbon Dioxide Emissions Reductions for Energy-Efficient Technologies and Measures Applied to Thai Pulp and Paper Industry (Cont.)

Technology/Measure	Production (Mt/year)	Fuel Savings (GJ/t)	Electricity Savings (kWh/t)	Primary Energy Savings (GJ/t)	Carbon Savings (kgC/t)	Retrofit Cost of Measure (US$/t)	Annual Operating Cost Change (US$/t)
Papermaking							
Gap forming	4.9	0	0.15	0.3	3.5	70	0.7
High consistency forming	4.9	1.5	0.15	2.43	18.2	70	0.7
Extended nip press (shoe press)	4.9	0.61	0	2.28	14.4	37.6	2.2
Hot pressing	4.9	0	0	0.87	5.5	25.7	0
Direct drying cylinder firing	4.9	1.05	0	1.5	9.5	111.2	1.4
Reduced air requirements	4.9	0.76	0.02	1.12	7.5	9.5	0.1
Waste heat recovery	4.9	0.5	0	0.71	4.5	17.6	1.6
Condebelt drying	4.9	1.6	0.07	2.43	16.7	28.2	0
Infrared profiling	4.9	0.7	-0.08	0.84	3.8	1.2	0
Dry sheet forming	4.9	5	-0.75	5.59	21.2	1504	0
General Measures							
Optimization of regular equipment	4.9	0	0.1	0.2	3.4	N/A	1
Energy-efficient lighting	4.9	0	0.05	0.1	1.6	1.2	-0.01
Efficient motor systems	4.9	0	0.62	1.25	19.6	6	0
Pinch analysis	4.9	1.79	0	2.54	16.1	8	0
Efficient Steam Production and Distribution							
Boiler maintenance	4.9	1.26	0	1.79	11.3	0	0.06
Improved process control	4.9	0.54	0	0.76	4.8	0.4	0.08
Flue has heat recovery	4.9	0.25	0	0.36	2.3	0.7	0.09
Blowdown steam recovery	4.9	0.23	0	0.33	2.1	0.8	0.11
Steam trap maintenance	4.9	1.79	0	2.54	16.1	1.2	0.09
Automatic steam trap monitoring	4.9	0.89	0	1.27	8	1.2	0.16
Leak repair	4.9	0.54	0	0.76	4.8	0.3	0.03
Condensate return	4.9	2.68	0	3.81	24.1	3.8	0.54
Fiber Substitution							
Increase use of recycled paper	2.1	13.4	2.1	22.4	186	485	-73.9

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Similarly, the specific carbon emissions reduction costs – Cost of Avoided Carbon (CAC) –will be defined as total net annual costs divided by the annual emissions avoided, due to implemented energy efficiency measures:[8]

CAC = (Annualized Investment + Annual Change in O&M Costs) / Annual Carbon Avoided (4)

III. Results and Discussions

A. *The Specific Energy Consumption (SEC)*

The result of specific energy consumption (SEC) reflects an efficiency of energy consumption and cost of energy for industry. The determination is on the article of what changes in manufacturing energy consumption are caused by changes in energy efficiency of the production process. Table 4 summarizes of the specific energy consumption (SEC) which is divided into into the specific heat consumption (SEC_h) and the specific electricity consumption (SEC_e). The SEC of the paper-making process is hardly affected by whether the paper mill is integrated or not. The SEC is affected by the type of energy carrier (e.g., wood chips or natural gas) and the method of energy generation (e.g., black liquor recovery boiler or cogeneration plant). SEC_h and SEC_e differ considerably per type of paper. The table shows that the specific electricity consumption (SECe) of sanitary paper and the specific heat consumption (SECh) of pulping are higher than other product whereas both of the specific energy consumption of box and packaging is lowest. Therefore, there is much more chance to decrease the energy consumption in pulp and sanitary paper compare to the other.

Table 4 The specific energy consumption (SEC)

Types of Product	The specific energy consumption (SEC)	
	SECe (kWh/ton)	*SECh (MJ/ton)*
Pulp	523	13,525
Kraft paper	640	5,757
Duplex board	780	6,992
Printing & writing paper	625	6,688
Sanitary Paper	1,823	9,227
Newsprint paper	844	4,593
Box and packaging	131	1,291

B. *The Conservation Supply Curve (CSC)*

The energy conservation supply curve shown in Figure 2 is a snapshot of the total annualized cost of investment for all of the efficiency measures being considered at that point in time. The technical potential for energy savings reflects the total area under the curve represented by all the measures examined in this analysis.

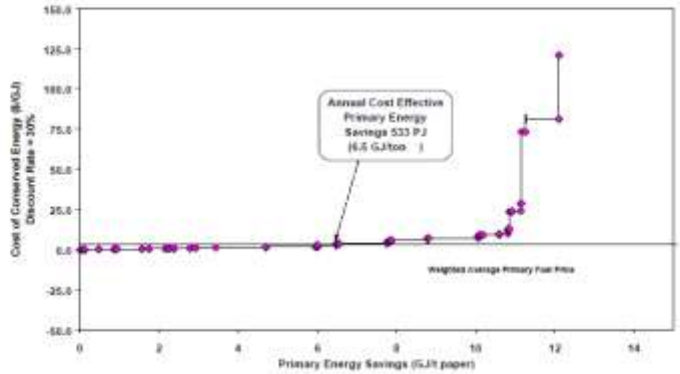

Figure 2 Energy Conservation Supply Curve for Thai Pulp and Paper Industry

The cost-effective potential reflects those efficiency investments which have a CCE lower than the average price of energy ($4.3/GJ)[4]. We identify a cost-effective energy savings potential of 533 PJ of primary energy consumption. The actual cost-effective energy savings may be higher, since not all of the energy-saving technologies and measures mentioned are included due to a lack of available data on investment and O&M costs of these technologies. The calculation of average energy prices was based on data from the U.S. Manufacturing Consumption Survey. About 10 PJ of primary energy savings can be achieved at negative cost.

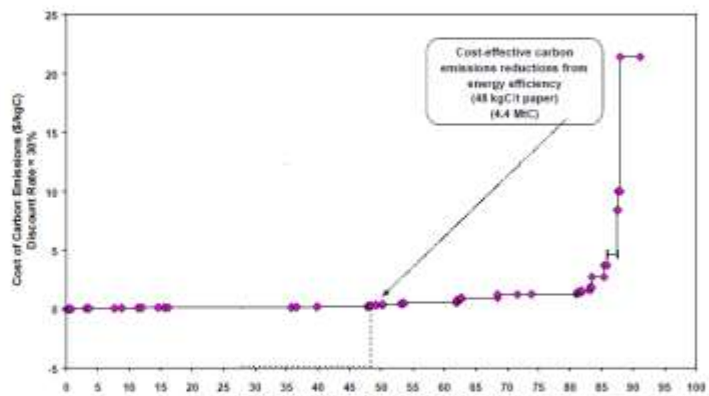

Figure 3 Carbon Dioxide Emission Reduction Supply Curve for Thai Pulp and Paper Industry

Carbon dioxide emission reductions associated with the implementation of all identified measures was estimated at 7.6 MtC. Most of the reductions are due to measures that reduce fuel or steam use by the various processes. Some of the largest technical potential savings identified are in chemical pulping (especially new digester technology), papermaking (new drying technologies) general plant-wide measures, and boiler efficiency measures. As indicated by the term technical potential, not all of the measures identified can be achieved cost effectively at the current energy prices. Following the methodology for the energy conservation supply curve, the authors constructed carbon dioxide emission reduction supply curve for the pulp and paper industry (see Figure 3). Similar to the conservation supply curve for energy savings, the cost-effective potential for carbon dioxide emissions can be determined. The difference between the two curves is determined by the carbon intensity of the fuel mix. Due to the large share of biomass in the fuel mix, the relative effect of the energy efficiency measures on emission reduction will be lower compared to that for energy use. Using the average energy prices the cost effective level of carbon dioxide emissions reductions was where the cost of conserved carbon fell below $0.25/kgC. As figure 3 indicates, cost- effective carbon dioxide emissions reductions were estimated at 4.4 MtC.

IV. Conclusion

Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings in the face of ongoing energy price volatility. Many companies in pulp and paper industry have already accepted the challenge to improve their energy efficiency in the face of high energy costs and have begun to reap the rewards of energy efficiency investments.

Although the Thai pulp and paper sector has increase its energy use, a large technical potential still exists to further reduce energy intensity. There is an opportunity reduce the energy use according to high of the result of specific energy consumption (SEC). In addition, this analysis of pulp and paper industry reviews about 40 specific energy-efficiency technologies and measures, and assesses energy savings, carbon dioxide savings, investments costs and operation and maintenance. Using a conservation supply curve methodology, we identify a total cost effective reduction of 6.3-6.5 GJ/t of paper. This is equivalent to an achievable energy savings of 16% of pulp and paper primary energy use and 14% of pulp and paper carbon dioxide emissions (corresponding to a reduction of almost 48-49 kgC/t of paper).

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