◆◆ **Scientific**
◆◆ **Research**

Energy and Carbon Modeling with Multi-Criteria Decision-Making towards Sustainable Industrial Sector Development in Thailand

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ABSTRACT

This paper develops some policy options for Thailand's industrial sector. The energy simulation model, the Long-range Energy Alternatives Planning (LEAP) system, has been used to simulate how energy might develop from 2005-2030. Five policy interventions are selected, and how these would change energy development is examined, and compared to a reference case. Further, the industrial policy options are assessed using a multi-criteria decision-making framework. Results of this study can increase the knowledge and understanding to make an explicit consideration of the transition from high carbon intensive energy system to one which is substantially decarbonized. The most significant energy-savings are improvement of energy efficiency and process integration. These policy options also have the large potential to reduce CO_2 emissions.

Keywords: *CO_2 Emissions, Energy Modeling, Industrial Sector, Multi-Criteria Decision-Making*

1. Introduction

Climate change and energy issues are demanding new efforts to addressing the challenges. Significant changes have taken place on the world energy scene, which have important implications for energy planning. Globally, the industrial sector accounts for 40% of primary energy demand and approximately the same share for CO_2 emissions. Mitigation can be substantially cut in this sector through policies, initiatives and efficient energy technologies. Thailand's industrial sector consists of manufacturing, mining and construction industries. The manufacturing industry accounts for more than 90% of total energy consumption in the industrial sector. Besides, the manufacturing industry contributes about 95% of CO_2 emissions from industrial sector, while construction and mining industries contribute the rest [1]. Therefore, preparing appropriate actions can significantly reduce energy demand and associated CO_2 emissions.

There are few studies of energy scenarios in Thailand, particularly in the industrial sector, make an explicit consideration of the transition from high carbon intensive energy system to one which is substantially decarbonizes. This paper is motivated by the need to help decision-makers to prepare scientific-based policy, and to analyze

industrial energy demand and associated emissions in a sustainable way. The paper would provide an in-depth understanding of the complex dynamics of energy and CO_2 issues related to structure of industrial energy use patterns. In addition, it can produce a scientific knowledge to aid decision-makers in preparing with pathway towards low-carbon economy. Planning for a low-carbon society requires processes of analysis and decision-making about what resources and technologies to be used and pathways to achieve.

This paper aims to develop energy and carbon modeling of Thai industrial sector and some policy options. It outlines and assesses the current status and future development related to energy consumption and CO_2 emissions over the twenty-five years from 2005-2030. The simulation model, the Long-range Energy Alternative Planning (LEAP) system, is used to simulate what might happen to energy demand and carbon emissions in the future in a business-as-usual (BAU) case and with alternate scenario. The BAU scenario provides a baseline vision of how energy consumption and CO_2 emissions are likely to evolve, while alternate scenario explores a range of policy interventions. The study goes further in applying a decision support tool to evaluate different

policy options based on multi-criteria decision-making (MCDM) approach. The scope of this paper is focused on only manufacturing industries, including food and beverages, textiles, wood and furniture, paper, chemical, non-metallic, basic metal, fabricated metal, and others (unclassified).

2. Background Information of Thailand's Industrial Sector

The industrial sector is extremely diverse and includes a wide range of activities. Thai industry has grown significantly over the past two decades. Industrial value-added has increased from 255.5 billion Thai Baht in 1981 to 1,043.2 billion Thai Baht in 2000 at constant 1988 prices. Manufacturing industry has a dominant share and its importance has increased from about 80% in 1981 to above 91% in 2000. The growth rate of manufacturing value-added accelerated from 5% to 15% per year between the first and second half of the 1980s, and continued to grow rapidly by 11% per year in the first half of the 1990s. This was primarily due to the growth of manufacturing exports. As a result, manufacturing's contribution to overall gross domestic product (GDP) increased rapidly from 23% to 31% between 1980 and 1995. This performance came to an abrupt halt in 1996, when manufacturing exports declined. In the period 1996-2000, manufacturing value-added and exports grew by an average of 3% and 2% per year.

Thai manufacturing industry has undergone some structural changes during 1981-2000. Food and beverage was among the largest contributors to the manufacturing sector value-added in the early to mid-1980s. The share of the export-oriented textile industries peaked during late 1980s. Two groups of industries have gained in shares: other industries and chemical industries. The industrial sector has begun the largest energy consuming sector in Thailand since 2005 [2]. By fuel types, oil is the largest share of total final energy consumption. The gradual substitution of fuel-oil with natural gas and the slow growth in diesel demand result in the decline in the share of oil. Natural gas is expected to grow faster rate. Thai government has policies to improve energy efficiency and the shift of the industrial structure from energy intensive to non-energy intensive industries. Within manufacturing sector, CO_2 emissions from food and non-metallic industries dominate over others. Food industry accounted for about 49% of CO_2 emissions in 1981 but its share has fallen to 29% in 2000. Shares of non-metallic industry and chemical industry in CO_2 emissions have increased from about 24% and 5% in 1981 to 27.5% and 13% in 2000, respectively. Thus, food, non-metallic and chemical industries account for about 70% of CO_2 emis-

sions [1].

3. Methodology

3.1. LEAP Model

Energy modeling is an important part of the methodology. Various energy models are available to develop policy cases quantitatively and to provide a consistent framework of their analysis. LEAP is a simulation model for energy planning tool. It is not a model of a particular energy system, but rather a tool that can be used to create models of different energy systems. The central concept of LEAP is an end-use driven model in which users create quantitative descriptions of current and future energy demand and supply and environmental scenarios. The model includes the Technology and Environmental Database (TED), which provides extensive information on the technical characteristics and environmental impacts of energy technologies [3].

This paper looks into the development pathways of energy consumption and energy-related CO_2 emissions, and the potentials of reducing energy consumption and emissions in Thai manufacturing industries. The model is disaggregated in a hierarchical tree structure of four levels: sector, sub-sector, end-use, and device. The main driver in energy consumption is the production of commodities. The disaggregation introduces physical energy intensities in terms of energy use per ton of industrial product produced for a portion of the industrial sector. The energy demand is formulated as a function of GDP, proportion of energy utilization, device efficiency, and useful energy intensity. The useful energy intensity is estimated as follows:

$$UEI_j = \sum_t \frac{(EnU_{i,j} \times \eta_{i,j})}{GDP_j}$$

where UEI_j represents the energy intensity in industrial sub-sector j (ktoe/10^6 Baht), $EnU_{i,j}$ is the energy type i utilized in sub-sector j (ktoe), $\eta_{i,j}$ is the efficiency of equipment using fuel type i utilized in sub-sector j, and GDP is gross domestic products of industrial sub-sector j (10^6 Baht).

3.2. Multi-Criteria Decision-Making

A framework of the MCDM method used in this study can be seen as two main phases. In the first phase, decision team decides on the criteria they want to use and determine their relative importance. In this paper, the selection of main criteria and sub-criteria are followed the study conducted by [4]. In the second phase, the decision group applies the MCDM method to judge the relative merits of the alternatives. This is done by deter-

mining scores for each alternative for each criterion using the measuring scales defined in the first phase.

The application of MCDM was carried out in a laboratory setting. Five people with a background in energy, engineering, economic, environment, and political were contacted and communicated. They were asked to imagine themselves to be the decision-makers in charge of making decisions. One of the authors was assigned as the resident MCDM expert, that responsible for organizing the information and following other processes. Thus, other members do not need to become familiar with the mechanics of aggregating the information and running MCDM calculation.

The objective of the study is to propose sustainable energy system. The criteria for energy system assessment reflect three main aspects, including environmental, economic and social. Some criteria and sub-criteria are quantifiable, while others are qualitative. The performance prediction is done based on computer simulation (energy modeling), databases, rules of thumb, and experience or expert judgment. Qualitative values are words or phrases that can be used to characterize how well a scheme rates against a particular criteria. These are quality issues, such as public acceptance or integration into an urban context. The criteria weights are determined using a mathematical technique so-called Analytic Hierarchy Process (AHP). AHP enables to structure

a complex problem in the form of hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple conflicting criteria. AHP makes use of pairwise comparisons with 9-point ratio scaling to apply weights to attributes. Computer software Web-HIPRE (Hierarchical PREference analysis on the World Wide Web) is used in this process. For more detail of Web-HIPRE see [5,6] and the AHP see [7-9].

4. Scenario Definition

4.1. Scenario Description

Energy model allows the construction of policy options in a quantitative way. The implication of policy interventions can be tested. In order to demonstrate the future energy consumption and CO_2 emissions, and to evaluate the benefits of energy policies, two scenarios were developed in LEAP model under different sets of policy options–a reference scenario or BAU case and an alternate policy scenario. These scenarios are primarily governed by four factors: economic growth, proportion of energy types, efficiency of energy devices, and energy intensity. The policy options and assumptions are given in **Table 1**.

Scenario provides a framework for exploring future energy perspectives, including various combinations of

Table 1. Policy options and assumptions for scenario generation.

Scenario	Policy options	Assumptions
Business as usual		Historical trends will continue and the GDP growth rate 4.5% (2005-2010) and 5.5% (2011-2030).
Alternate policy	Improvement of industrial energy efficiency (IEE)	A target of 10% and 20% increasing energy efficiency by 2015 and 2030. These improvements are from compressed air, boiler and steam systems, and lighting systems.
	Switching to natural gas (ING)	Thermal energy supplied by non-renewable resources such as diesel and fuel-oil will be switched to natural gas by 2015.
	Combined heat and power in designate factories (ICHP)	Combined heat and power (CHP) systems will use to produce electricity in selected industries and the waste heat will use to replace heat from fuel-oil fired boilers. CHP systems will replace fuel-oil by 2015 and assume that electricity consumption will decrease 10% in each industry.
	Efficient electricity end-use devices (IElect)	Only electricity will be considered—availability of efficient and less energy intensive pumps, compressors and motors for industrial processes. This policy can consider as a part of Energy Labeling Program. It is assumed that increasing 20% of electricity efficiency by 2010.
	Process integration (IPI)	Process integration will apply to food and beverages, chemical and paper industries. It is assumed that 20% reduction in useful energy intensity by 2015.
	Integrated policy (IIP)	All of the above mentioned policies are considered together. This policy option would give the cumulative effect of the different options, giving Thai industry the lowest possible emission reductions.

technology options and their implications. The scenario analysis timespan covers the years 2005-2030. All scenarios start from a common base year (2005), which is named as the current account (CA) scenario in LEAP model. CA scenario describes energy demand in industrial sector based on proven historical data. Data for the CA scenario were collected from different sources as described in the following section. The CA scenario forms the base of BAU and alternate policy scenarios.

BAU scenario assumes that past trends continue in the future and no new policies for energy-savings and emission mitigation will be implemented. Energy demand is predicted as a function of time. This scenario aims to show the future through the prism of current policies and strategies. For the BAU scenario, the current patterns in the industrial structure will be maintained and the industrial sub-sectors will be the same as in CA scenario. This implies no change compared to the industrial structure in 2005.

The alternate policy scenario is inherited from BAU scenario. It is, thus, reflected sensitivities on the original scenario. This considers the cumulative impact of five industrial energy policies, including improvement of industrial energy efficiency, switching to natural gas, CHP in designate factories, efficient electricity end-use devices, and process integration. This scenario can also consider as a mitigation scenario, which means that more ambitious energy conservation and emission reduction objectives and relevant policies are adopted. The policy options form the basis for technology selection. LEAP converts the assumptions (**Table 1**) into quantitative way.

4.2. Data Sources

This study draws on a wide variety of sources. Data were obtained from various sources: statistical information, government publications of official energy data, utility statistics, journal articles, book chapters, research reports, and others. The principle sources are Ministry of Energy [2,10] and Ministry of Industry [11-12]. Sources of data used on economic [13-14], energy [2,10,15-17], and technology issue [18-21]. Data obtained from the original source were processed to meet the input requirements in LEAP model to develop a base year dataset. Growth in GDP was assumed to be the same in all scenarios. We assumed Thailand's GDP from industrial sector will maintain its growth with an annual growth rate set to be 4.5% from 2005 to 2010. Then the growth will grow up, with an annual growth rate set to be 5.5% from 2010 to 2030. This assumption is based on the estimation by National Economic and Social Development Board. The industrial structure will remain constant during timeframe.

5. Results

5.1. Scenario Analysis Results

5.1.1 Business-as Usual Scenario

The BAU scenario represents a base case without policy interventions. It is a projection of what would happen in the absence of specific energy policy and strategy. Currently, industrial sector energy consumption accounts for around 36% of total national energy consumption, and the highly energy intensive industries, such as food and beverage, non-metallic and chemical, make up over 70% of total industrial energy demand. Detail results for BAU case are shown in **Table A-1**. It shows that total industrial energy demand in 2005-2030 will increase by 5.53% annually, and in 2030, the energy demand is estimated to be about 3.5 times of that of the year 2005.

Food and beverage, non-metallic and chemical industries are expected to grow rapidly in BAU scenario. Estimated renewable energy (including bagasse, biomass and wood), coal, electricity and natural gas demands in 2030 are 20,112 ktoe, 26,573 ktoe, 19,034 ktoe and 6222 ktoe, respectively. Shares of biomass, coal, electricity and natural gas in energy demand of 2030 are estimated to be 26.5%, 35%, 25% and 8.2%, respectively. Among non-renewable energy, coal, electricity and natural gas are primarily responsible for the majority of final energy demand (**Table A-1**).

The emissions for 2030 at BAU scenario are estimated 3.7 times for CO_2 compared to the base year 2005. It should be noted that emissions from biomass are not taking into account. Non-metallic and fabricated metal are responsible for majority of the emissions in 2030. Non-metallic is responsible for emitting about 29.5%, while fabricated metal emits about 17.8% of total CO_2 from industrial sector. CO_2 emissions are estimated to be 68 $MtCO_2$, 116 $MtCO_2$ and 198 $MtCO_2$ in 2010, 2020 and 2030, respectively. The estimations for the intermediate years are illustrated in **Figure 1**. Electricity and coal products are responsible for the majority of emissions.

5.1.2. Alternate Scenario

The alternative policy options are compared to the BAU case in order to assess their potentials of energy demand and CO_2 emission reductions. Indicators are selected to compare the results from the viewpoint of avoided energy demand and avoided CO_2 emissions compared to BAU case. The reduction in final energy demand in the industrial sector that occurs as a result of different policy options are shown in **Table 2**.

It is found that energy efficiency improvement alone would reduce energy demand by 40% from the BAU
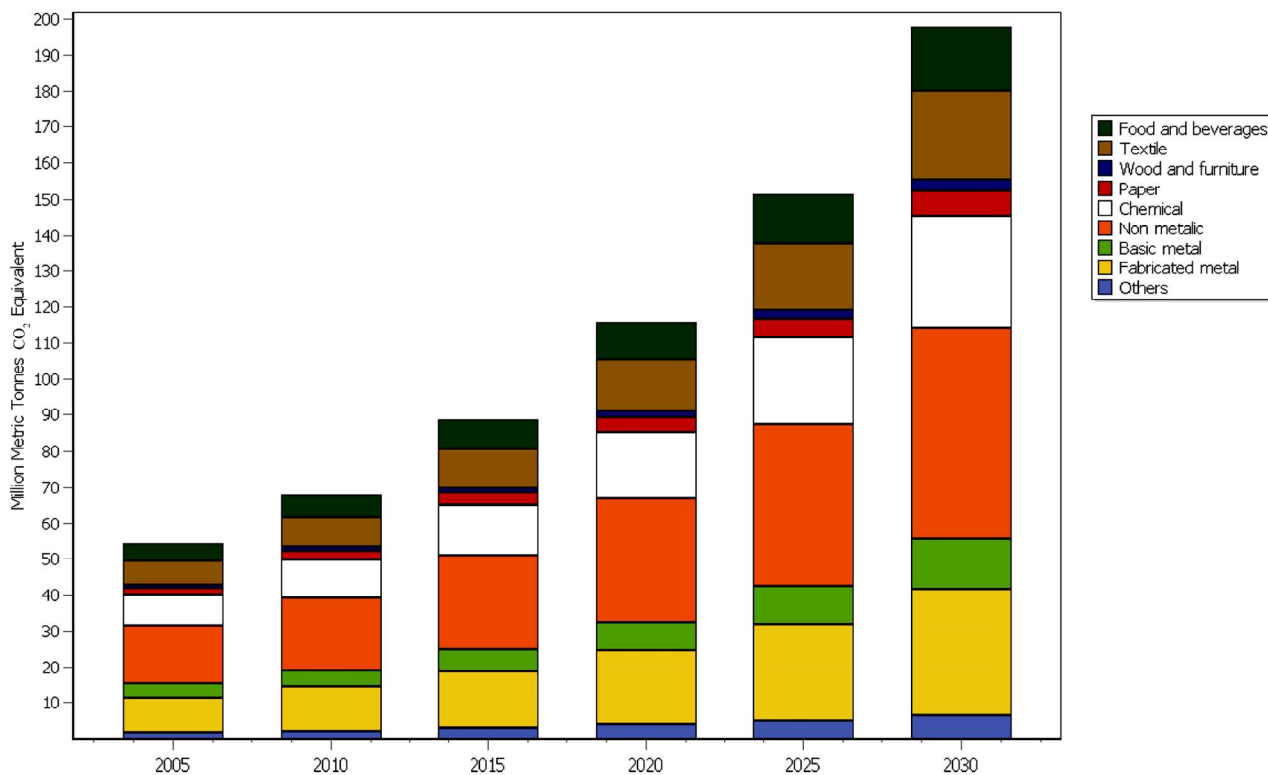
Figure 1. Estimated CO$_2$ emissions from industrial energy consumption in BAU case.

Table 2. Avoided energy demand compared to BAU under various policies (ktoe).

	2010	2015	2020	2025	2030
Energy efficiency improvement	1293	3379	5904	9661	15,168
Switching to natural gas	239	624	816	1066	1393
CHP in designate factories	505	1321	1725	2253	2943
Efficient electricity end-use	1087	1421	1857	2427	3172
Process integration	2599	6794	8880	11,606	15,168
Integrated policy	5723	13,539	19,182	27,013	37,844

Table 3. Reduction of CO$_2$ emissions in various policies from BAU case (MtCO$_2$).

	2010	2015	2020	2025	2030
Energy efficiency improvement	3.37	8.82	15.39	25.18	39.51
Switching to natural gas	0.95	2.49	3.25	4.25	5.56
CHP in designate factories	2.11	5.52	7.22	9.43	12.33
Efficient electricity end-use	7.21	9.42	12.31	16.09	21.03
Process integration	6.77	17.7	23.13	30.23	39.51
Integrated policy	20.41	43.95	61.3	85.18	117.94

case in 2030. The reductions of energy demand in this policy case are higher compared to the other measures, such as switching to natural gas, CHP in designate factories, and efficient electricity end-use devices. Process integration policy shows high possibility to reduce energy demand during 2010-2015. It is, however, due to the assumption in the model the potential reduction of energy demand decrease to 40% by 2030. Implementing all of the policy options is estimated to reduce energy demand by 22% in 2010, 43% in 2020, and 50% in 2030. Such reductions would have potentials to reduce a large amount of government revenues to be spent on imported energy. The potential CO$_2$ emission reductions in various policies are presented in **Table 3**.

5.2. Evaluation of Policy Options

There are five main criteria for this analysis, including resource use, environmental loading, financial and economic, social, and practical. Main findings are found that resource use and environmental loading equal importance on both criteria. It is also found that few differences between social and practical aspects. Among sub-criteria (see **Table 4**).

The annual fuel is considered to be the most important of the resource use criteria. The annual CO$_2$ emissions are evaluated as the most important and the annual SO$_2$ emissions is more importance than annual NO$_x$ emissions in the environmental loading criteria. The market maturity is found the least important of the four aspects of the

Table 4. Evaluation results of policy options.

Main criteria & Sub-criteria	Alt1	Alt2	Alt3	Alt4	Alt5
1.Resource use					
- Resource depletion	0.014	0.003	0.005	0.006	0.008
- Annual electricity	0.037	0.007	0.010	0.030	0.018
- Annual fuel	0.083	0.012	0.019	0.041	0.038
2. Enviromental loading					
- Annual CO_2 emissions	0.084	0.013	0.023	0.045	0.084
- Annual SO_2 emissions	0.012	0.004	0.005	0.011	0.023
- Annual NO_x emissions	0.012	0.002	0.002	0.006	0.006
3. Financial & economic					
- Construction cost	0.009	0.001	0.002	0.004	0.004
- Annual operating cost	0.023	0.004	0.005	0.023	0.010
- Annual maintenance	0.010	0.004	0.003	0.009	0.012
- Market maturity	0.003	0.001	0.003	0.001	0.001
4. Social					
- Job creation	0.002	0.006	0.004	0.002	0.002
- Public acceptance	0.015	0.003	0.004	0.012	0.012
- Human health impacts	0.013	0.002	0.001	0.006	0.008
- Integration in urban context	0.003	0.000	0.001	0.003	0.001
5. Practical					
- Political support exist	0.008	0.009	0.007	0.005	0.002
- Data available	0.003	0.001	0.001	0.003	0.000
- Maintainability	0.026	0.005	0.012	0.027	0.003
Overall	0.355	0.075	0.105	0.234	0.231

financial and economic criteria. The public acceptance is more significant than the other three social criteria and human health is more important than job creation. In the practical criteria, the maintainability is considered to be the most important than the other two criterions.

The alternatives consist of five policy options: improvement of industrial energy efficiency (Alt1); switching to natural gas (Alt2); combined heat and power in designate factories (Alt3); efficient electricity end-use devices (Alt4; and process integration (Alt5). Alternatives were evaluated based on their subjectively estimated contribution to each criterion. The results of evaluation are presented in **Table 4**. Five policy options are prioritized with respect to the overall score of each

alternative, which is computed by multiplication of its scores for criteria with the corresponding weights obtained by AHP. Energy efficiency improvement policy was evaluated to be the most competitive for industrial energy policy with a score of 0.355, followed by efficient electricity end-use policy and process integration policy with a slightly lower score. Policy for CHP in designate factories was form the fourth priority. Switching to natural gas policy was ranked the lowest.

6. Conclusions

This paper applied energy modeling and multi-criteria assessment to develop, and evaluate a set of policy options which explore a range of technical, managerial and behavioral options for Thailand's industrial sector. The overall research question is whether there are energy policies to make the development in Thailand's industrial sector more sustainable economically, socially and environmentally. A contribution of this paper lies in combining energy model and MCDM approach to identify industrial policy options that can promote and prepare pathway towards low-carbon economy.

Results from the modeling study shows that under the BAU scenario the industrial energy demand would be 75,945 ktoe by 2030 and the CO_2 emissions are estimated to be 198 $MtCO_2$ in the same year. Among energy-related CO_2 emissions from industrial sector it is found that electricity and coal are the main sources of emissions. In the alternate scenario, the energy efficiency improvement and process integration have great potential to reduce energy demand and CO_2 emissions as well as improve the local air pollutants as co-benefits relative to the BAU scenario. These policies have the potential of energy-savings of 30,336 ktoe and 79.02 $MtCO_2$ emission reductions in 2030. These amounts of energy-saving are important for Thailand, since the country depends upon imported fuels. Nevertheless, if all industrial policy options are simultaneously implemented, the highest potential of energy-savings in 2030 is expected to be 37,845 ktoe. There would be a reduction of 117.94 $MtCO_2$ by 2030.

The prioritization of five industrial policy options was carried out by AHP and Web-HIPRE. The study developed a three-level hierarchy structure, with five main criteria, and evaluated the importance and the competitiveness of each policy option. The evaluation of industrial energy policies can be concluded that the energy efficiency improvement and is ranked highly in all dimensions of sustainable development with a score of 0.355. The findings suggest that efficient electricity end-use devices and process integration have priority for policy interventions. Results of modeling and evaluating

policies provide useful, policy-relevant information, and can be used as a basis for priority policy planning in the industrial sector.

7. Acknowledgements

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Table A-1. Energy demand of industrial sub-sector in BAU case (ktoe).

	Coal				Petroleum Product				Natural Gas			
	2005	2010	2020	2030	2005	2010	2020	2030	2005	2010	2020	2030
Food and Beverage	0.1	0.1	0.2	0.3	162	202	345	589	7	8	14	24
Textile	-	-	-	-	66	82	140	238	5	6	10	17
Wood and Furniture	-	-	-	-	4	6	9	16	-	-	-	-
Paper	141	176	300	513	73	91	156	267	-	-	-	-
Chemical	796	992	1695	2895	75	93	159	271	1127	1404	2398	4097
Non-metallic	5818	7251	12,386	21,156	18	22	38	65	425	529	904	1544
Basic Metal	41	51	87	148	60	75	128	218	-	-	-	-
Fabricated Metal	-	-	-	-	9	11	19	33	141	176	301	514
Others	512	638	1090	1861	553	689	1177	2010	7	9	15	26
Total	7308	9107	15,557	26,573	1020	1271	2171	3708	1711	2132	3642	6222
	Renewable[*]				Electricity				Total			
	2005	2010	2020	2030	2005	2010	2020	2030	2005	2010	2020	2030
Food and Beverage	5331	6644	11,349	19,385	669	833	1423	2431	6169	7687	13,131	22,430
Textile	-	-	-	-	979	1220	2084	3559	1049	1307	2233	3815
Wood and Furniture	2	3	5	8	130	162	277	472	137	170	291	496
Paper	-	-	-	-	174	217	370	632	388	484	826	1412
Chemical	32	40	68	116	846	1055	1802	3078	2876	3584	6121	10,456
Non-metallic	247	308	526	899	492	614	1048	1790	7001	8724	14,902	25,455
Basic Metal	-	-	-	-	542	675	1153	1970	643	801	1368	2,337
Fabricated Metal	-	-	-	-	1399	1743	2977	5085	1549	1930	3297	5632
Others	-	-	-	-	4	5	9	15	1076	1341	2291	3913
Total	5613	6994	11,947	20,408	5235	6523	11,143	19,034	20,887	26,028	44,460	75,945

[*]Renewable energy is including bagasse, biomass and wood.