CHAPTER 2

REVIEW OF RELATED RESEARCH AND LITERATURE

2.1 Environmental impact from PV manufacture

Not much work has been done on the impact from PV manufacture especially in terms of CO_2 emission. To know the CO_2 emission, we must know the energy required by each process needed to complete a PV panel, then the amount of energy is converted to the amount of CO_2 emission.

Alsema et al. (1989) investigated the energy requirements of manufacturing PV modules and systems for using crystalline silicon. For multi-crystalline panels the energy required is equal to 4,200 to 11,600 MJ (primary energy) per m^2 and is equal to 6,000 to 13,900 MJ for single crystalline for the low and high estimation. The difference between low and high energy requirement is that the low estimate is based on the lower end value for silicon purification and does not include a primary crystallization step while the high estimation assumes the high end value for silicon purification and includes 2,400 MJ per m^2 of cell surface for the primary crystalline step.

Brookhaven National Laboratory and the National Renewable Energy Laboratory (1998) mentioned that PV CO_2 emission is zero during use because PV systems require little or no maintenance or oversight. Some CO_2 emission can be attributed to manufacturing because it takes energy to manufacture a module.

Besides the problem of CO_2 emission from PV manufacture, some environmental effects must be considered, such as those from the toxic chemicals which are used in the manufacturing process and yield hazardous wastes. Tsuo et al. (1998) studied the toxic chemicals used in PV manufacturing and found that the manufacturing of silicon devices from polysilicon, crystal growth, ingot silicon, wafer cleaning and devices processing to encapsulation requires many steps that are energy intensive and uses a large amount of water and toxic chemicals. To reduce the large amount of toxic wastes and resulting pollution, manufacturers must reduce energy used and/or the purchase volume of new chemicals and cut the amount of used chemicals that must be discarded.

2.2 The effect of energy on the environment

In the manufacturing processes for a PV panel, electrical energy must be put into the process. This amount of electrical energy is the source of CO_2 emission. Therefore, to estimate CO_2 emission from PV manufacture we must estimate it based on the electricity input for the manufacture. Soponronnarit. et al. (1999) studied the CO_2 emissions from electricity generation sector in Thailand and found that the fuels used in electricity generating are fuel oil, diesel oil, natural gas, lignite and imported coal. If the combustion of the fuel is assumed complete, the amount of CO_2 emitted from the electricity generation sector will be 24.841 and 64.967 million tons or 0.575

and 0.486 kg CO_2/kWh, respectively. CH_4 emission from production of natural gas and lignite is equivalent to CO_2 emission of 1.594 and 3.390 million tons in 1990 and 2010. In the fuel combustion process, the combustion is assumed to be complete so all of the carbon content in the fuels is changed to be CO_2, that the imported coal is Anthracite. CO_2 emission from the mining of natural gas estimated from the equation 'fugitive methane emission' which is equal to the amount of mined natural gas (PJ) multiplied by an emission factors (kg/PJ) and there are three ranges of emission factors:

1. Production	46,000 - 96,000	kg/PJ
2. Venting and flaring	175,000-209,000	kg/PJ
3. Processing and transmission high emission factor	288,000	kg/PJ

The estimation of CO_2 emission from coal mining used the 'coal mining emission' which is equal to the amount of mined coal (M tons) multiplied by the emission factor 0.3-2.0 m^3/tons and the conversion factor 0.67 $Gg/10^6$ m^3 at 20 ^{0}C 1 atm. The electricity generation from hydrocarbon fuels (fuel oil, diesel, natural gas, lignite and imported coal) with a completely combustion process emitted CO_2 equal to 3.13 tons/tons of fuel oil, 3.17 tons/tons of diesel, 2.36 tons/tons of natural gas, 1.21 tons/tons of lignite and 3.179 tons/tons of anthracite. If imported coal was used, the total emission of CO_2 in the year 1990-2010 would be expected to equal 24.841 and 64.967 M tons which is equal to 0.575 and 0.486 kgCO_2/ kWh. The component of each kind of fuels used in Thailand and the consumption of fuels for electricity production and the resulting CO_2 emission are shown in Tables 1 and 2.

Table 1. Compositions and some properties of different kinds of fuels per weight (%). (Soponronnarit. et al., 1999)

	C	H	O	N	S	Ash	Heat Value (MJ/kg)	kg CO_2 /kg fuel
Fuel oil	85.5	10.5	1.5	0.4	2.0	0.1	42.98	3.131
Diesel	86.5	12.8	0.1	0.1	0.5	-	45.20	3.172
Natural gas	64.3	33.2	-	2.5	-	-	45.00	2.357
Lignite	31.1	2.2	9.9	1.1	1.4	22	12.80	1.140
Anthracite	86.7	2.2	2.9	0.8	0.5	6.9	33.90	3.179

Table 2. Consumption of fuels for generating electricity and CO_2 emission.
(Soponronnarit. et al., 1999)

	Unit	Actual		Forecast		
		1990	1994	2000	2004	2010
Natural gas	GWh	18,056.88	3,0391.31	69,829.00	7,2816.0	66,909.0
	M tons	3.232	5.418	11.291	11.753	10.393
	CO_2 (M tons)	7.620	12.770	26.613	27.702	24.493
	Kg CO_2 / kWh	0.422	0.420	0.381	0.380	0.366
Fuel Oil	GWh	9,076.310	19,294.20	3,738.00	5,421.0	12,258.0
	M tons	2.157	4.38.	1.006	1.357	2.787
	CO_2 (M tons)	6.754	13.725	3.149	4.249	8.726
	Kg CO_2 / kWh	0.745	0.711	0.842	0.784	0.712
Diesel	GWh	259.730	1,627.720	25.000	248.00	313.00
	M tons	0.104	0.420	0.014	0.083.	0.122
	CO_2 (M tons)	0.330	1.333	0.044	0.263	0.387
	Kg CO_2 / kWh	1.272	0.819	1.760	1.060	1.236
Lignite	GWh	10,229.84	14,060.36	14,387.00	16,518.0	16,991.0
	M tons	8.889	12.288	13.067	14.979	15.263
	CO_2 (M tons)	10.134	14.008	14.896	17.076	17.400
	Kg CO_2 / kWh	0.991	0.996	1.035	1.033	1.024
Imported Coal	GWh	-	-	-	-	13,840
	M tons	-	-	-	-	4.391
	CO_2 (M tons)	-	-	-	-	13.958
	Kg CO_2 / kWh	-	-	-	-	1.008
Hydro Power	GWh	4,858.000	3,431.000	3,925.000	4,556.00	5,478.00
Buy	GWh	691.000	801.000	2863.000	2863.00	17746.0
Total	GWh	43,162.76	69,605.86	94,767.0	102,422	133,535
Total	CO_2 (M tons)	24.841	41.836	44.702	49.290	64.967