CHAPTER IV
RESULTS AND DISCUSSION

4.1 Inventory Analysis for the Three Scenarios Under Study

Life cycle inventory (LCI) data were compiled for PVC production in the first two cases: fully integrated process and PVC compounding from imported VCM, from data supplied by corresponding Thailand industrial associations (Figures 4.1 and 4.2). The last case employed LCI data in the Ecoinvent database, which represent average PVC production in Europe as a reference.

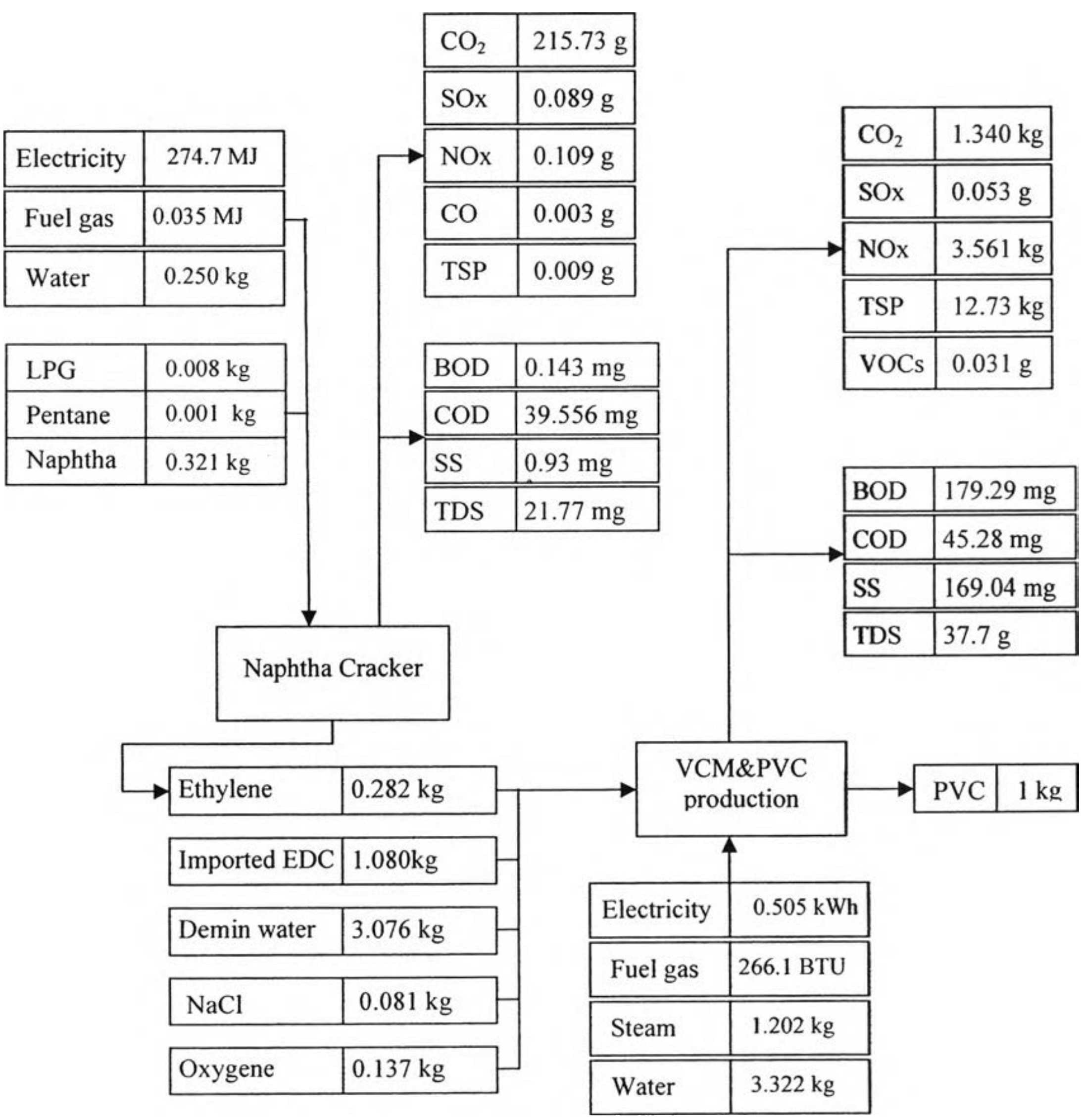

Figure 4.1 LCI data for a fully integrated PVC-production process.

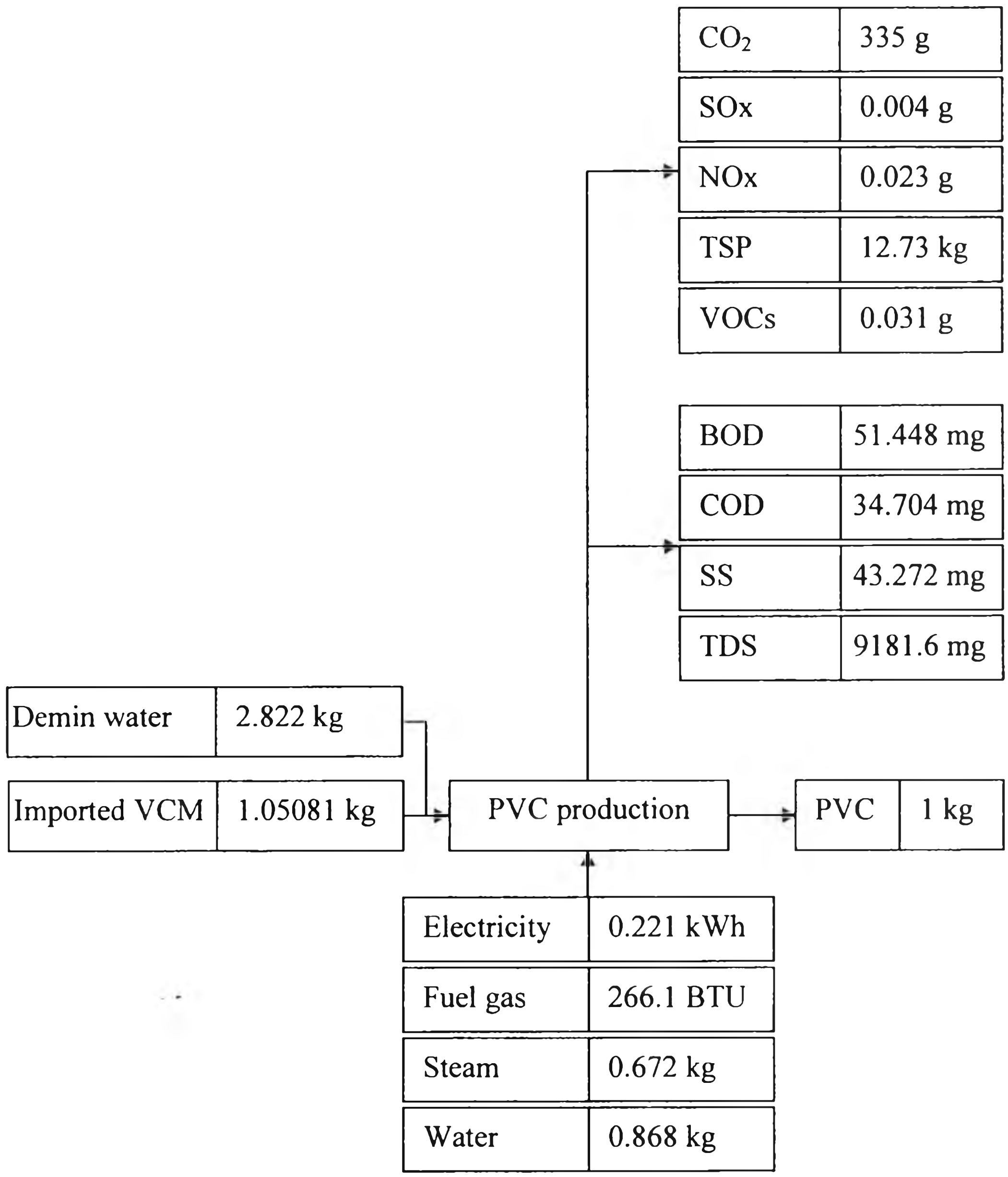

Figure 4.2 LCI data for manufacturing PVC from imported VCM.

The environmental loads associated with the production of 1 kg of PVC (from cradle-to-gate) in each case were tabulated and compared (Table 4.1 and Figure 4.3). Only three atmospheric emissions, namely CO_2, NOx and SOx, were reported here due to their major contributions to the overall environmental performance of petrochemical products in general.

Table 4.1 LCI data regarding air emissions from three scenarios

	CO_2 (kg)	NOx (g)	SOx (g)
Manufacture PVC from fully integrated process	39.1	3820	158
Compounding PVC from imported VCM	1.95	9.79	10.6
PVC imported from Europe	1.95	9.72	9.68

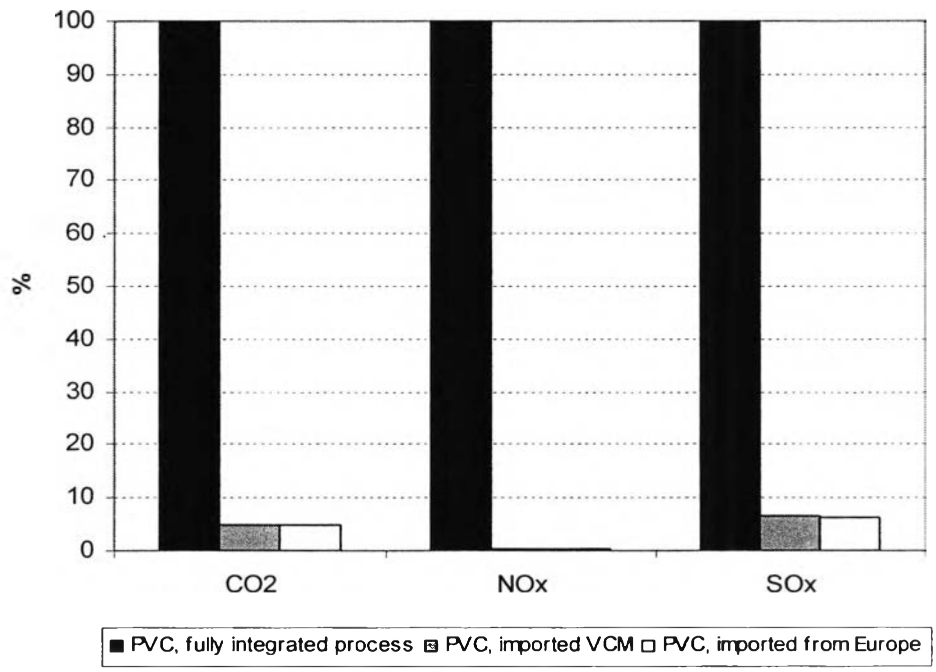

Figure 4.3 Comparison of air emissions of the three scenarios.

The life cycle inventory analysis for the three scenarios, focusing on atmospheric pollution, clearly shows that the amount of air emissions from fully generated process is to a great extent higher than that from other cases, particularly in the category of NOx. Compounding PVC from imported VCM and PVC manufactured in Europe register very analogous profiles throughout the three categories. This can be explained by the simplicity of the PVC compounding process and the complexity of the VCM synthesis process, particularly the electrolysis of NaCl to produce Cl_2.

To identify the sources of emissions from the fully integrated process, further analysis was conducted and the results are presented in Figures 4.4 and 4.5.

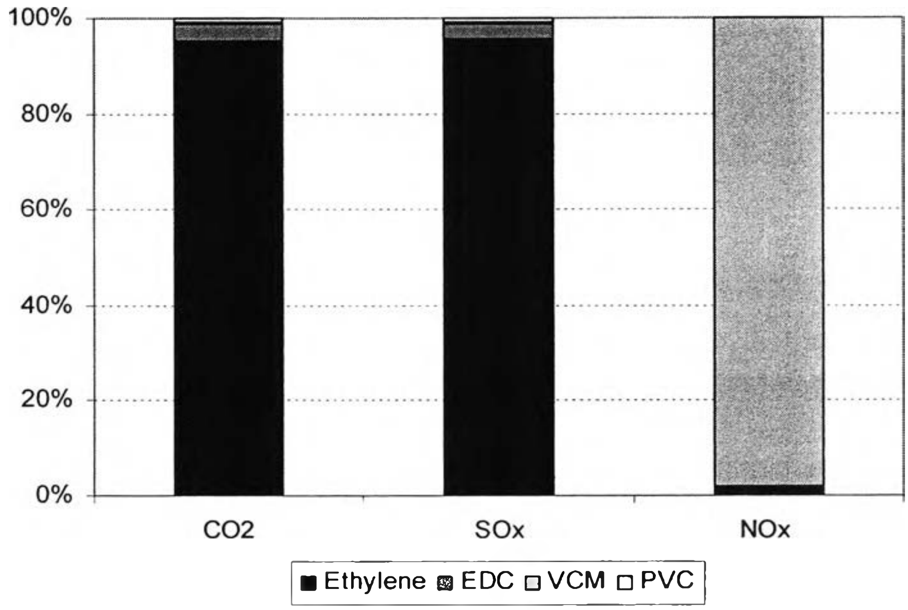

Figure 4.4 Comparison of emissions from different stages (upstream to downstream production) in the fully integrated process system.

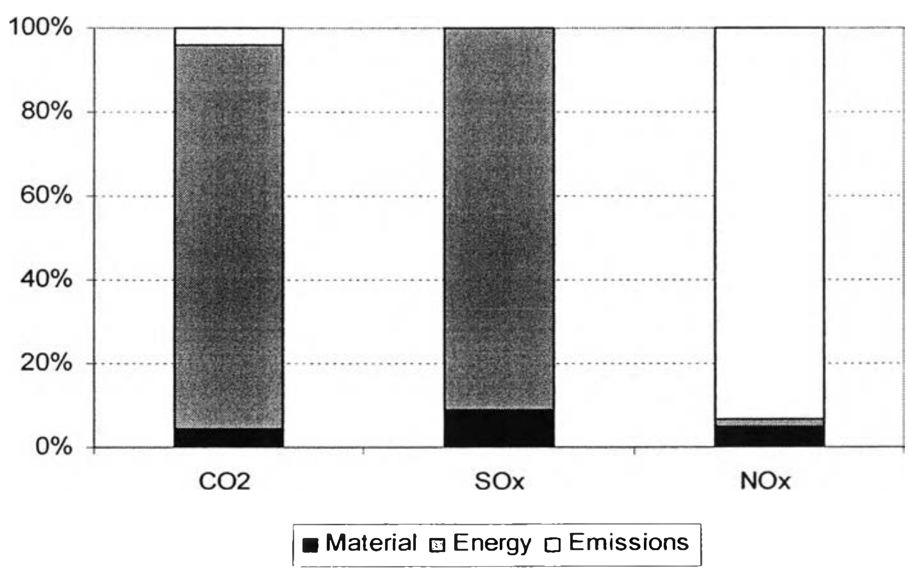

Figure 4.5 Comparison of emissions from different sources (the use of materials, the use of energy and the manufacturing process) in the fully integrated process system.

The emissions of CO_2 and SOx are both originated during the production of ethylene and due to the intensive use of energy as clearly shown in the above graphs. On the other hand, NOx is predominantly emitted during the manufacturing process of VCM production. Limited by the scope of this research, it is impossible to identify the specific hot-spots responsible for this excessive amount of NOx emissions. Further studies, focusing on the production of VCM, are vital in order to improve the environmental performance of the fully integrated process in Thailand.

4.2 Life Cycle Impact Assessment (LCIA) Results for the Three Scenarios

The LCI data for each scenario were translated into more meaningful environmental impact indicators, such as climate change, respiratory problem or resource (fossil fuels) depletion, by applying the Ecoindicator 99 assessment method. This methodology also includes a damage assessment step which extends the environmental impacts further to societal concerns or safeguard subjects, grouped into three damage categories: human health, ecosystem quality, and resources. The results of comparing impact categories and damage categories among the three scenarios are shown below in Figures 4.6 - 4.10.

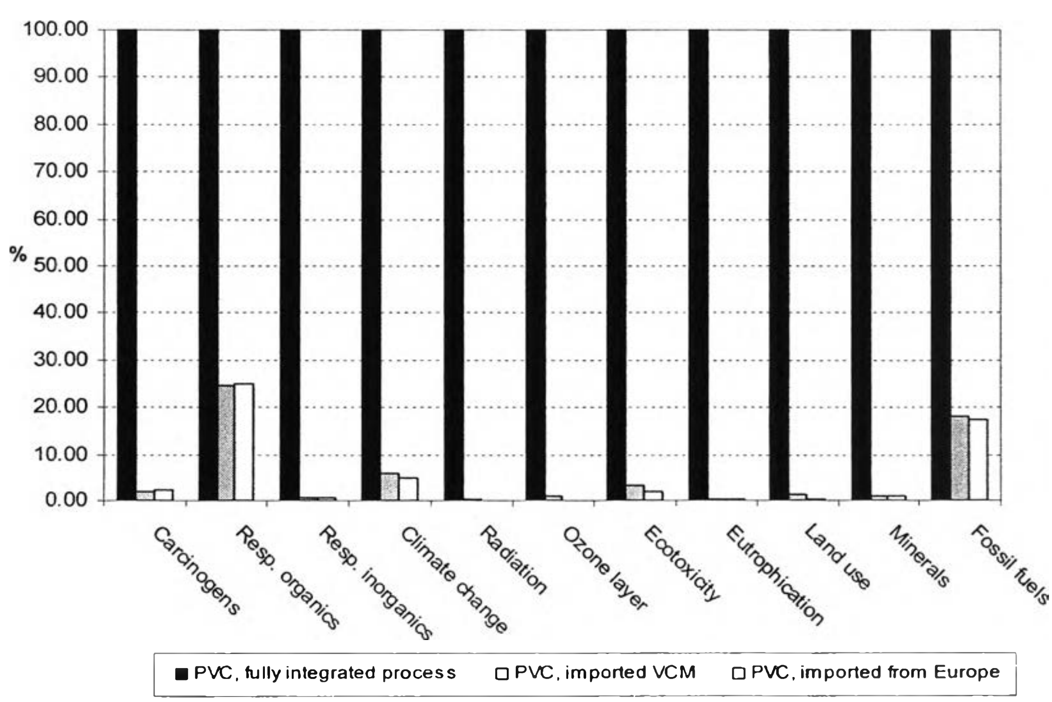

Figure 4.6 Comparison per impact category (mid-point categories).

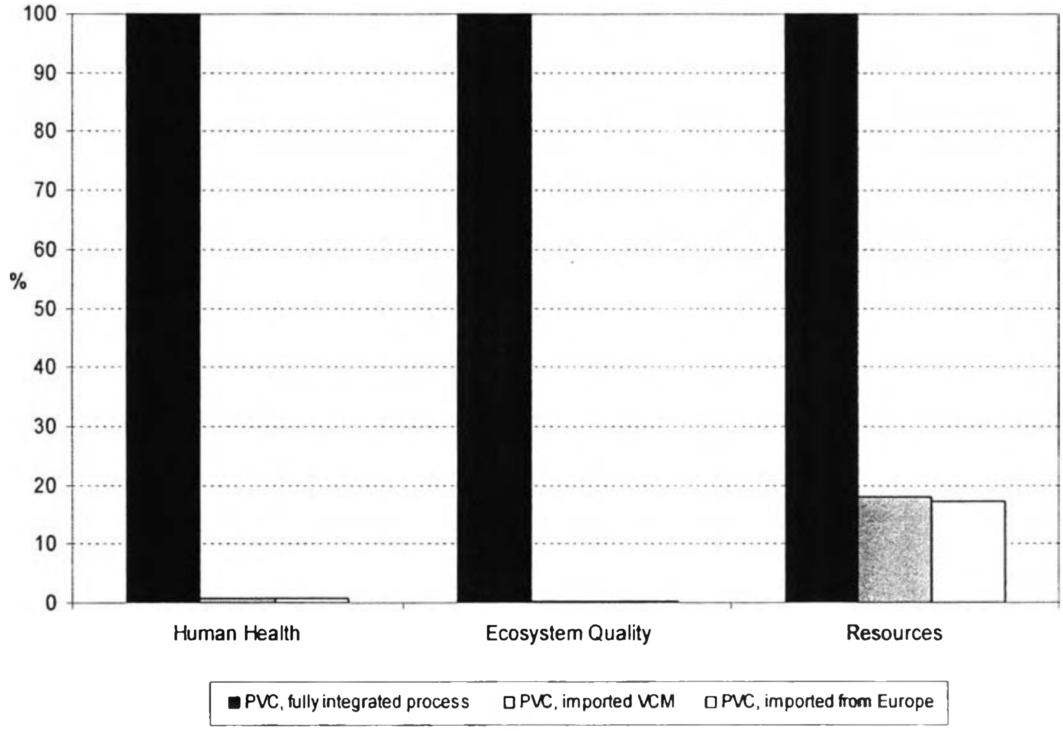

Figure 4.7 Comparison based on societal concerns (end-points).

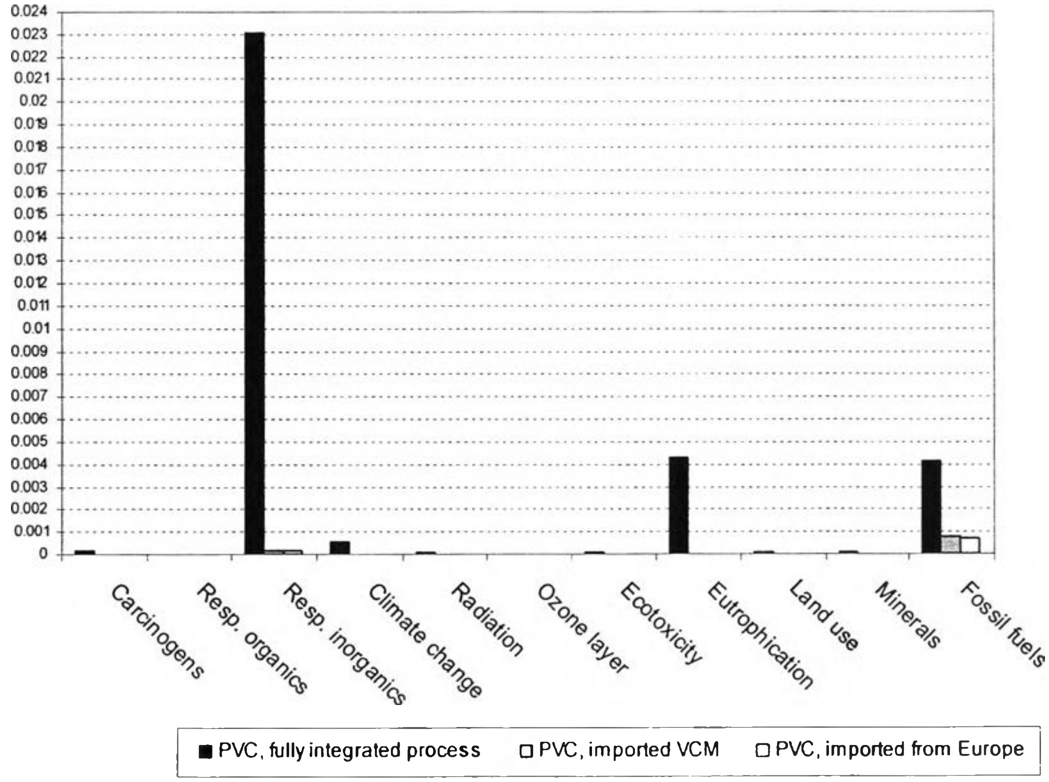

Figure 4.8 Comparison per normalized impact category.

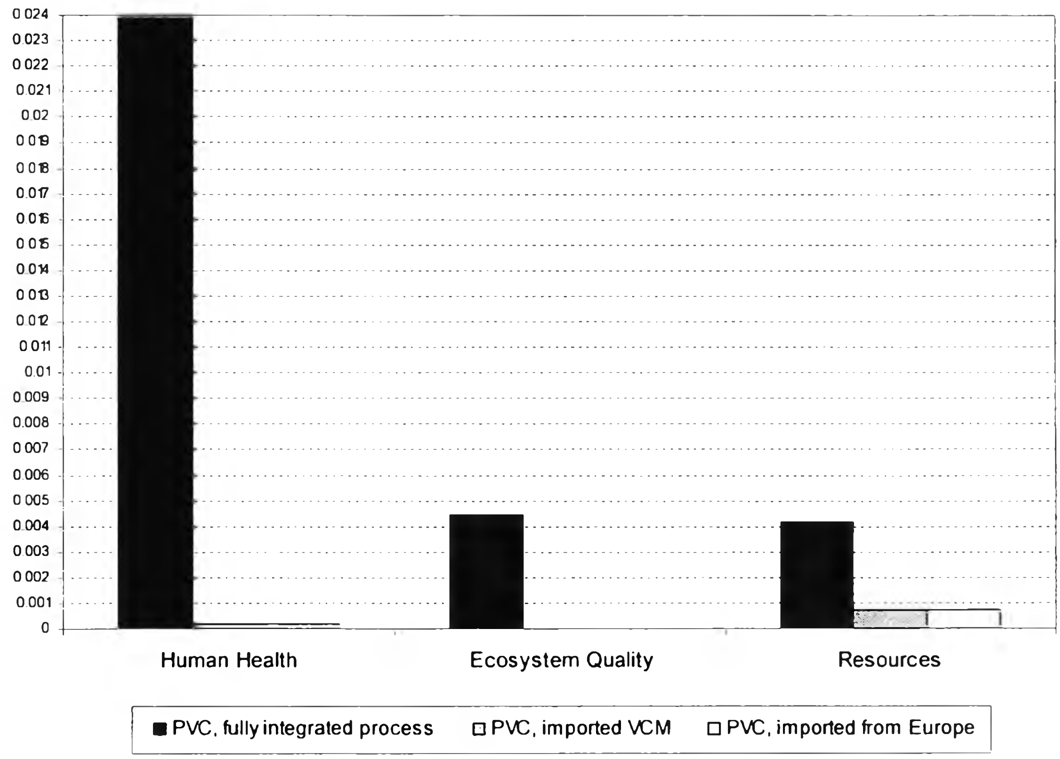

Figure 4.9 Comparison per normalized damage category.

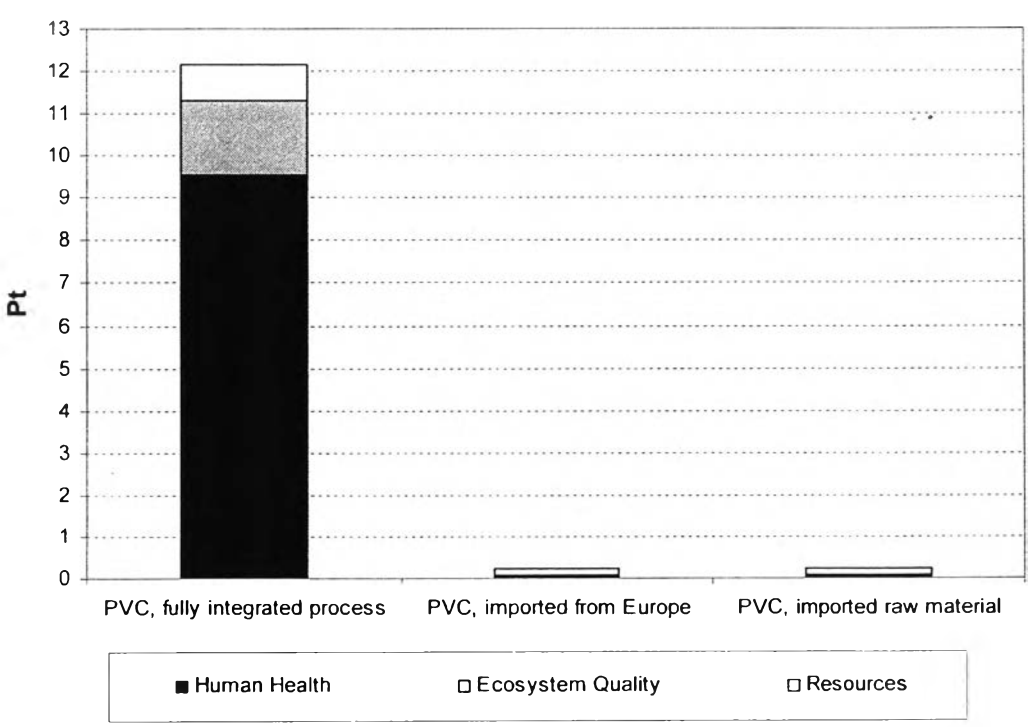

Figure 4.10 Comparison per single-score damage category.

Table 4.2 Process contribution to overall environmental loads

Process	Unit	PVC, fully integrated process	PVC, imported from Europe	PVC, imported VCM
Total of all processes	Pt	12.1	0.228	0.216
Vinyl chloride (VCM) process	Pt	10.3	x	x
Electricity	Pt	1.6	x	0.0044
Ethylene dichloride	Pt	0.132	x	x
Naphtha, at refinery	Pt	0.063	x	x
Steam, for chemical processes	Pt	0.0196	x	0.0107
LPG	Pt	0.00191	x	x
Ethylene	Pt	0.00172	x	x
Fuel gas (Natural gas)	Pt	0.00169	x	x
Refinery gasoline	Pt	0.00126	x	0.00111
Pentane, at plan	Pt	0.000424	x	x
PVC (fully integrated)	Pt	0.000415	x	x
Water, demineralized, at plant	Pt	5.74E-06	x	5.25E-06
Water, decarbonized, at plant	Pt	2.22E-06	x	5.19E-07
Vinyl chloride, at plant (Source: Europe)	Pt	x	x	0.198
PVC (Source: Europe)	Pt	x	0.228	x
PVC (imported VCM)	Pt	x	x	0.00191

Among the three analyzed scenarios, the fully integrated process to manufacture PVC from Ethylene and NaCl apparently has the poorest environmental performance in all respects, markedly in the "respiration of inorganics" category, which results in severe damage to human health. After that, in descending order of magnitude, eutrophication, fossil fuel depletion and climate change are major problems associated with the fully integrated process. Overall, the environmental loads brought about by this process are over fifty times as serious as those of the other two.

The scheme of importing VCM as raw material to manufacture PVC is roughly comparable to PVC production in Europe. Both of them showed very similar profiles across the impact categories, in which depletion of resources (fossil fuel) remained the major concern.

As a result of the above interpretations, the production of VCM is the primary cause for poor environmental performance of the integrated process to produce PVC in Thailand, particularly during the process of manufacturing VCM, which accounts for more than 85% of the total loads as illustrated in Table 4.2 (the rest are attributed to the use of raw materials). This also agrees well with the conclusion from the Final Report on Life Cycle Assessment of PVC (European Commission, 2004). Furthermore, according to the LCI analysis, it can be learned that the excessive amount of noxious NOx in air effluent is liable for that respiratory problem.

4.3 Improvements Analysis for PVC Production

As discussed above, the main source of problems occurring in the PVC production system comes from VCM and earlier stages (from middle-stream upwards). Thus, we can either improve the environmental performance in these two stages (process-wise, upstream and middle-stream processes) or increase the use of other sources of raw material which have less environmental burdens, such as imported VCM in this case. For the latter option, three different cases, using the present situation as a baseline, were analyzed. Presently, the ratio of imported and domestic VCM currently is 12.4:87.6 (source PTIT), and thus it was increased to 30:70 and 40:60 in two proposed scenarios. LCA analysis was then applied for comparison and the results are presented in the following graphs (Figures 4.11 - 4.15).

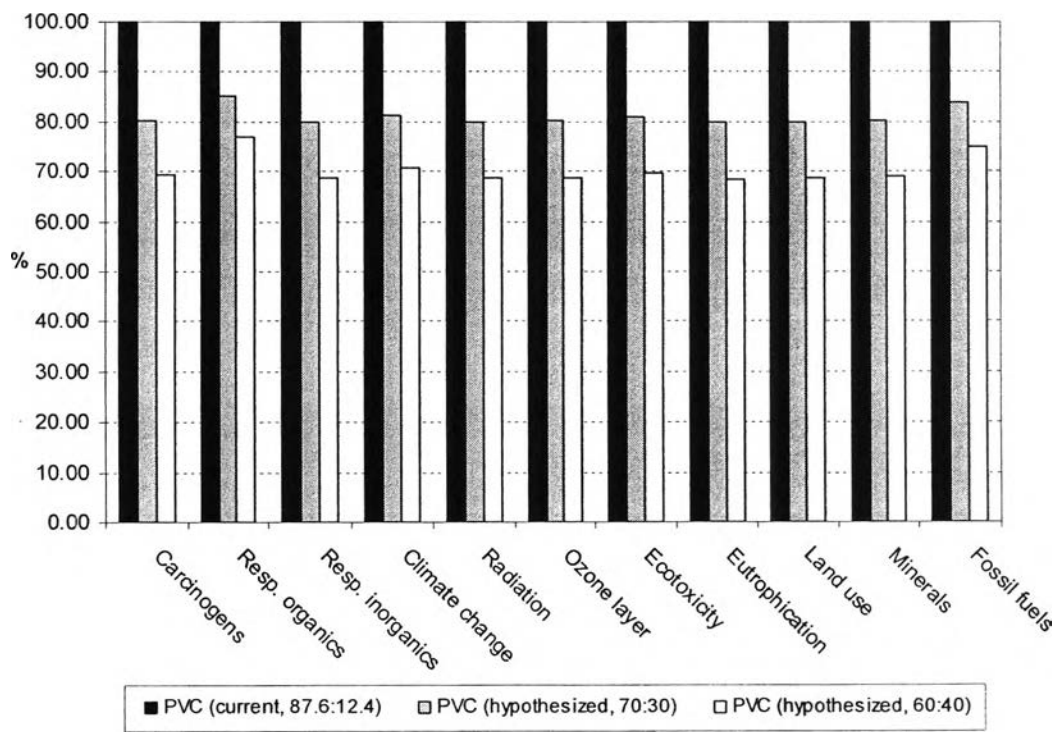

Figure 4.11 Comparison per impact category among different ratios of domestic and imported VCM in PVC production.

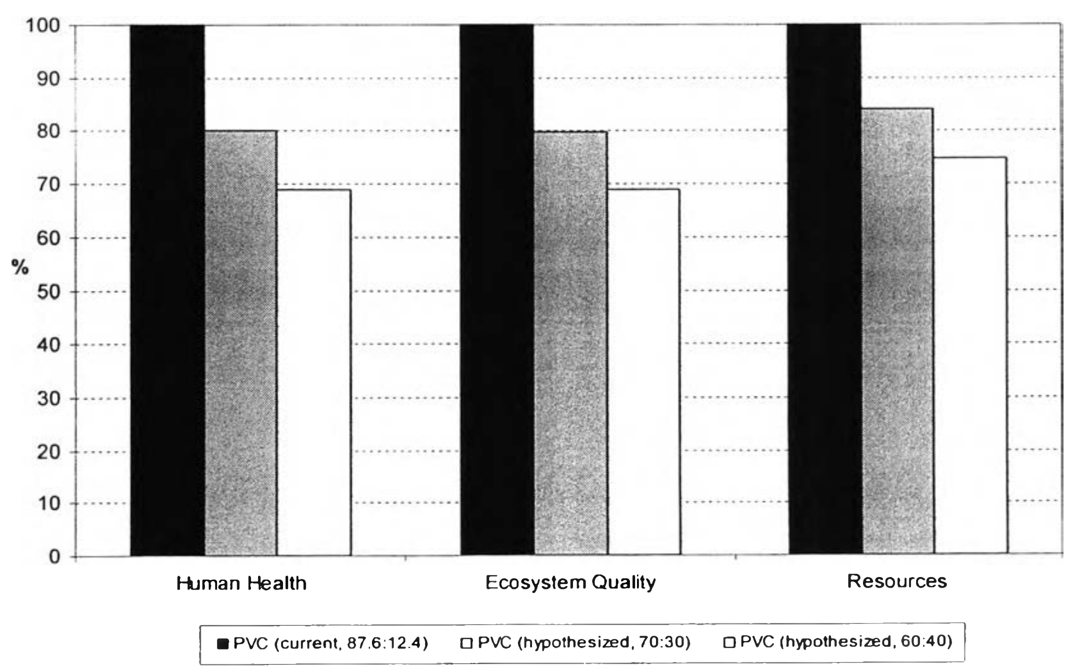

Figure 4.12 Comparison per damage category among different ratios of domestic and imported VCM in PVC production.

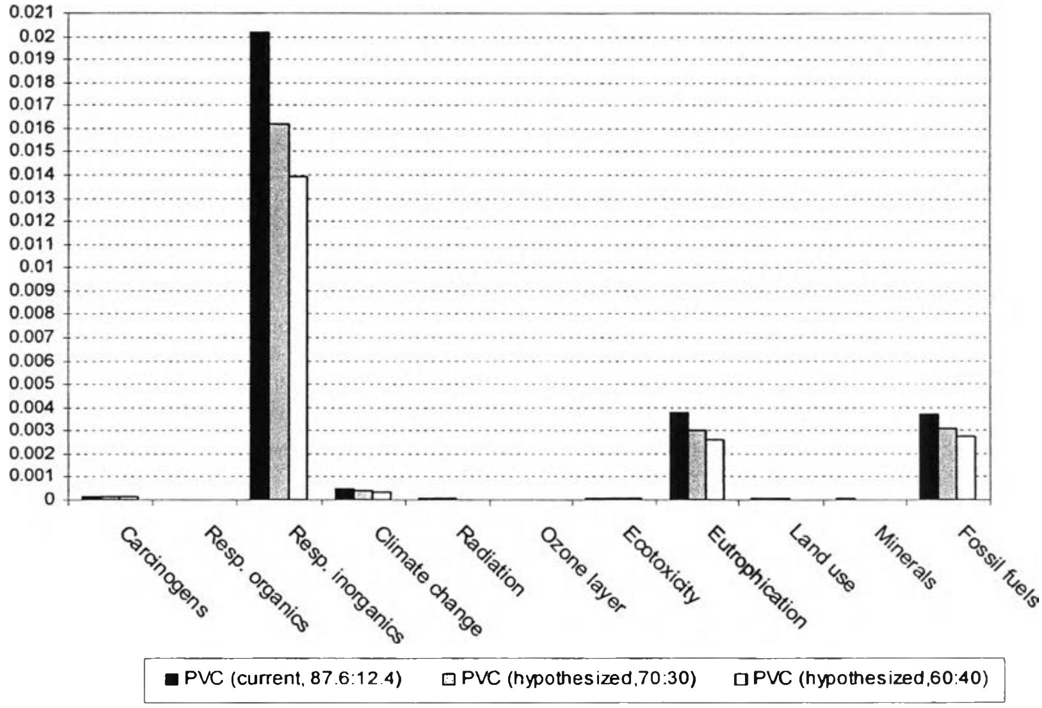

Figure 4.13 Comparison per normalized impact category among different ratios of domestic and imported VCM in PVC production.

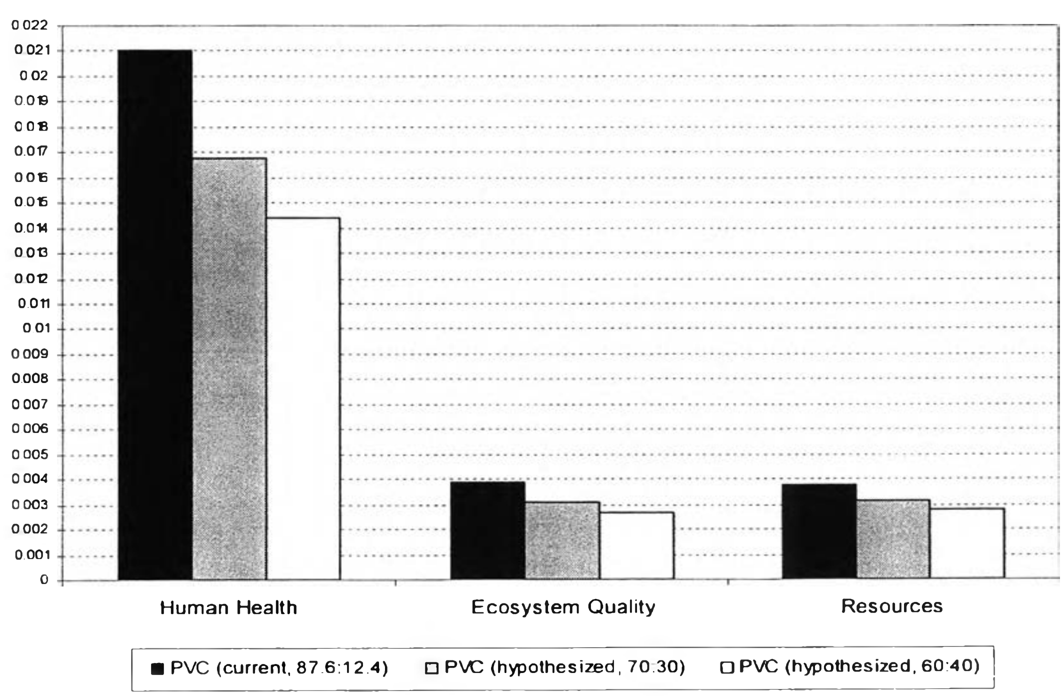

Figure 4.14 Comparison per normalized damage category among different ratios of domestic and imported VCM in PVC production.

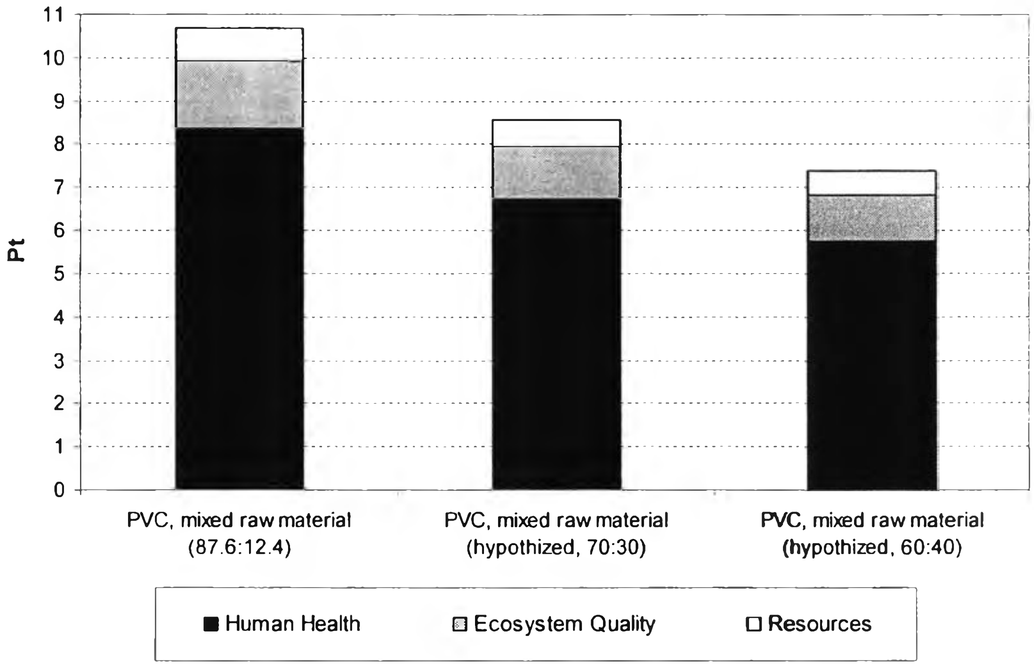

Figure 4.15 Comparison per single-score damage category among different ratios of domestic and imported VCM in PVC production.

According to the analysis results, by increasing the percentage of imported VCM in feedstock, from 12.4% to 30%, the overall environmental performance of PVC production can be enhanced considerably by 20%, with the corresponding decrease in all the relevant environmental impacts. Furthermore, the improvement can be boosted up to 30% when the ratio between imported and domestic VCM was shifted to 40:60, as illustrated in Figure 4.15.

This shift in imported and locally manufactured VCM also provides extra benefit in terms of saving one of the most important resources of Thailand – natural gas for producing ethylene. Utilizing imported VCM may help to prolong the service time of the local natural gas resource, which is limited in capacity and intensely demanded by the energy production sector. However, it is advisable that other factors, such as the economic and social impacts, which were beyond the scope of this study, should be carefully taken into consideration when implementing such a change.