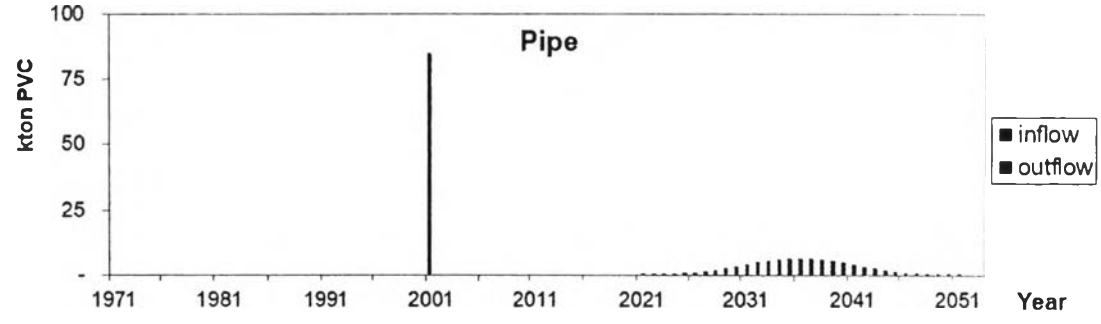
CHAPTER IV
RESULTS AND DISCUSSION

4.1 LC-MFA Model Results

Based on data of PVC product production in Thailand and the average service lifetime and service lifetime distribution given by AVC and industrial associations listed in Tables 3.5 and 3.7, these data were used in LC-MFA models as an input and how long PVC products are in use for both models of PVC construction products (Figure 3.6) and PVC household products (Figure 3.7). The data were test in two modes: single-year input and multiple-year inputs which are shown in following issues.

4.1.1 Analysis based on single-year input

After the PVC products are used in using phase for a certain years, they will become PVC waste and released to post-consumption phase. Based on the data of PVC products production in 2001 as shown in Table 3.5, the amount of PVC waste outflow to post consumption phase in following years can be calculated by using LC-MFA model. The results of PVC products inflow and outflow in each PVC products are shown in Figures 4.1 and 4.2. The profiles of outflow of each PVC products are different depending on the quantity of PVC products inflow, average service lifetime, and distribution of service lifetime. We can observe that there is only one time of PVC inflow, but there are several times of PVC product outflows because the service lifetimes of products are distributed as a normal distribution. For the long life PVC products such as pipe, profile, and cable, the position of graph of inflow and outflow are quite far from each other (20-30 years). In contrast, cable, floor tile, floor covering, shoes, and hose the graph of inflow and outflow of PVC products are closer than the case of PVC pipe and profile because these products are all the soft PVC products and short life PVC products.


Pipe
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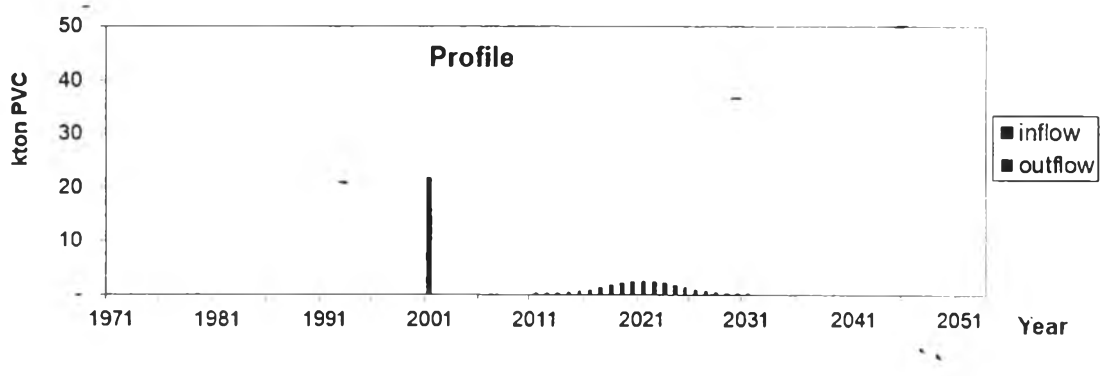
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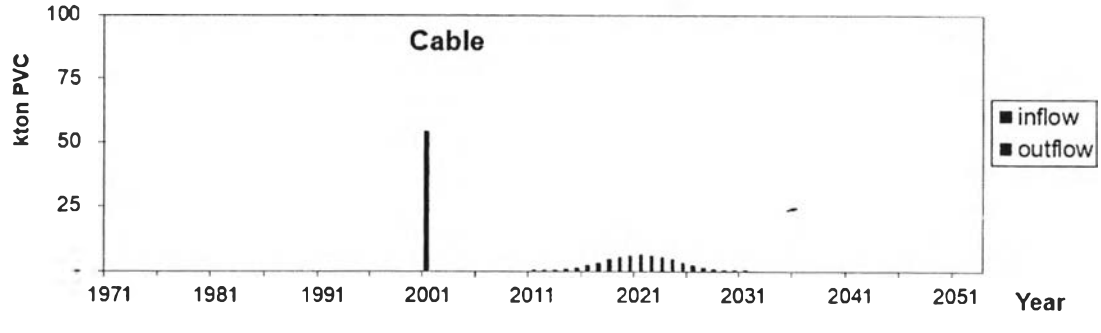
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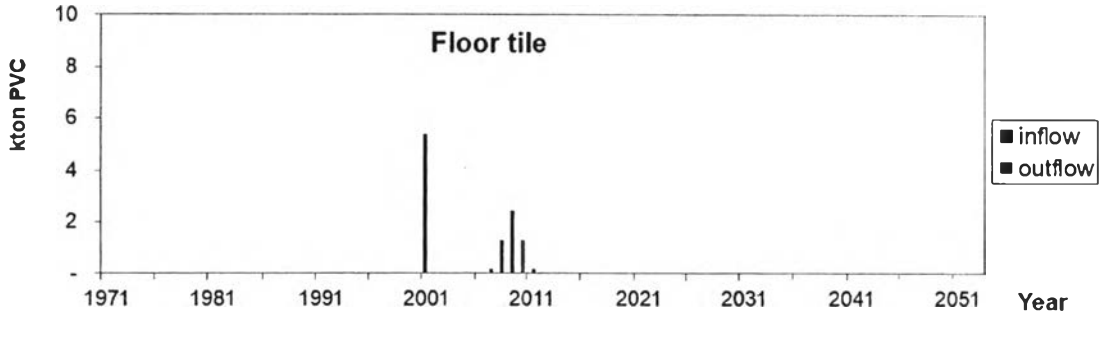
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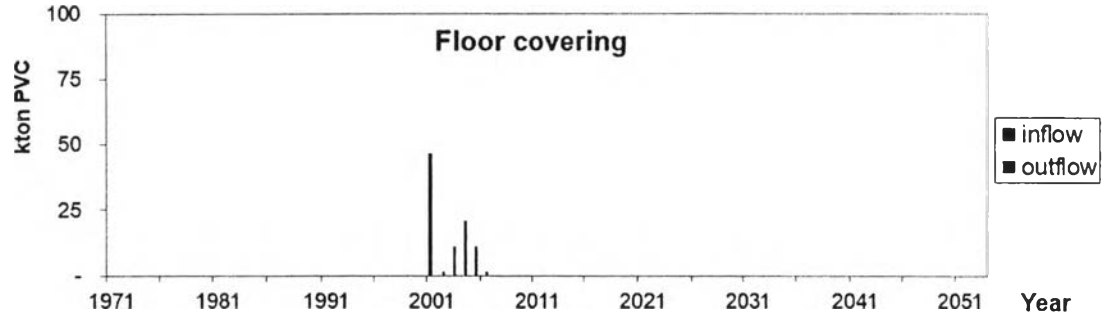

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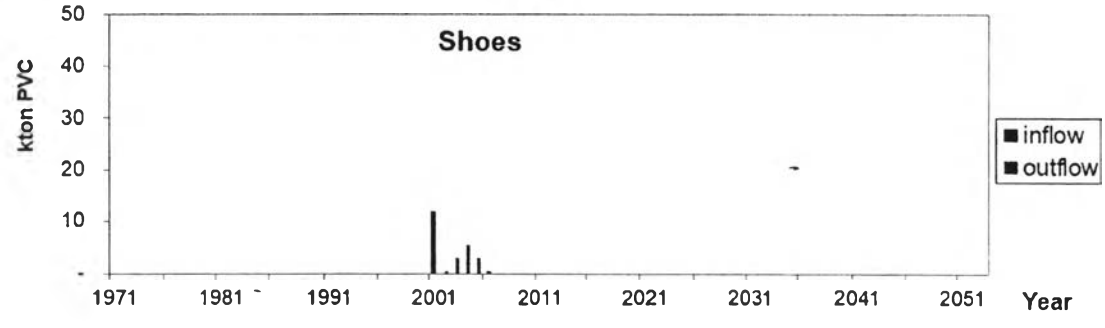

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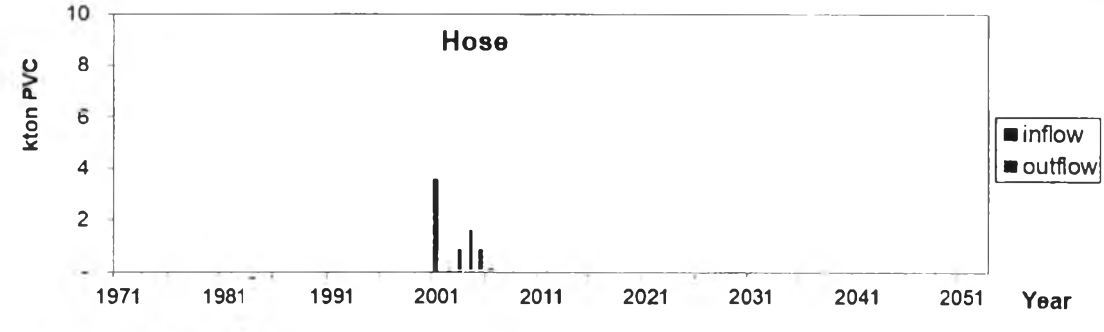


(g)

Figure 4.1 Annual outflow based on a single year input of PVC products; a: pipe and fitting, b: profile, c: cable, d: floor tile, e: floor covering, f: shoes, and g: hose.

The mixed PVC product outflows based on single year input are shown in Figure 4.2. From this figure, we can notice that there are three periods of waste outflows which have a significant amount of waste outflow. The first period is around three years after PVC products flow-in because at this time PVC floor

covering reaches its service lifetime, and it is released as a waste outflow. The second period is around 20 years after PVC products flow-in because at this moment PVC profile and cable are about to reach their end-of-life and become PVC waste. The third period is about 35 years after products flow-in because in this period PVC pipe and fitting reach the end of their service life and finally become PVC waste outflow.

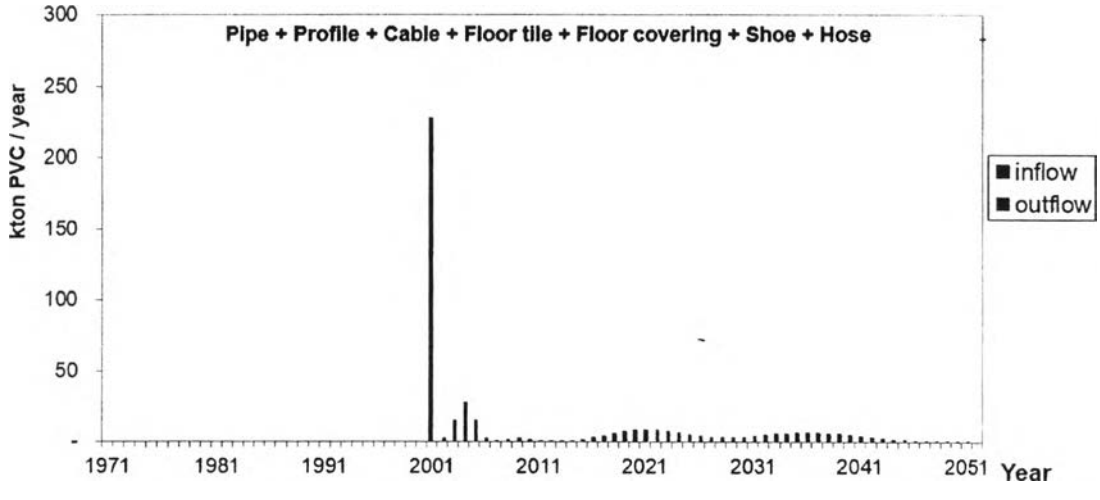
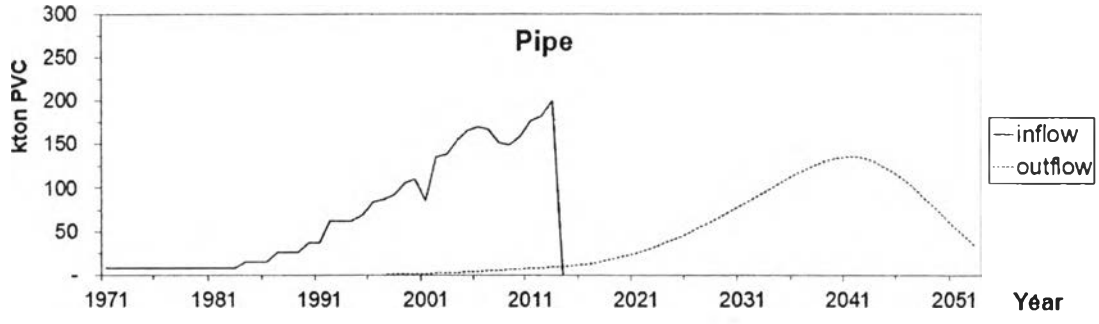


Figure 4.2 Annual emission based on a single year input of mixed PVC products.

4.1.2 Analysis based on multiple-year inputs

Based on the data of PVC production from 1971 to 2013 in Tables 3.5 and the average service life and service life distribution in Table 3.7, these data were used to run and test in LC-MFA model as a dynamic Material Flow Analysis. The amount of PVC product outflows in following years can be calculated by using these dynamic LC-MFA models. The results of inflows and outflows of the PVC target PVC products are shown in Figures 4.3 and 4.4 and Table 4.1.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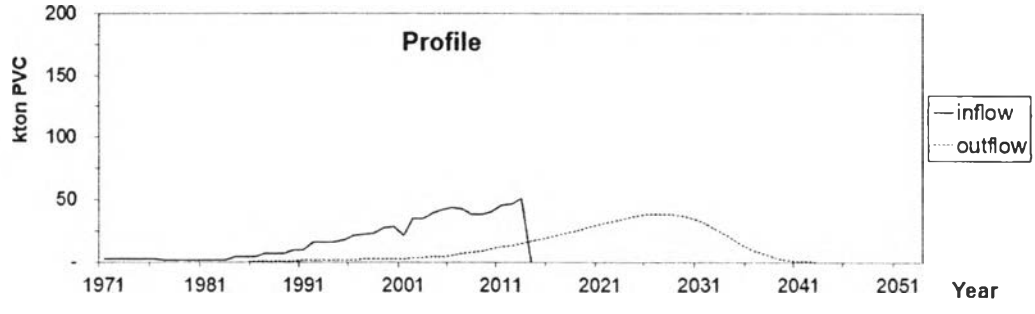
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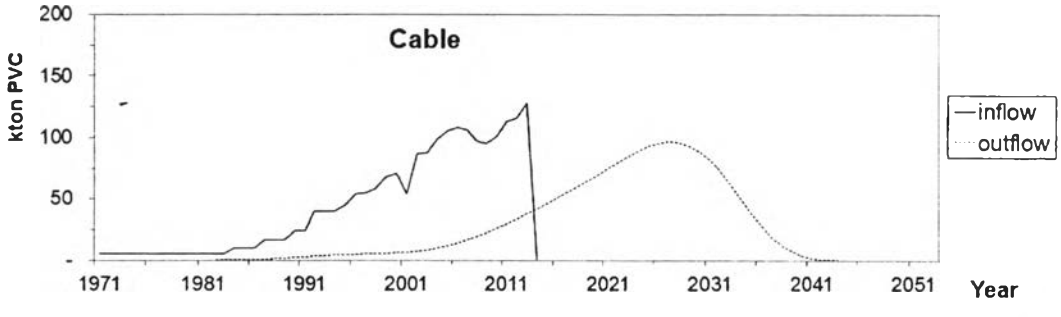
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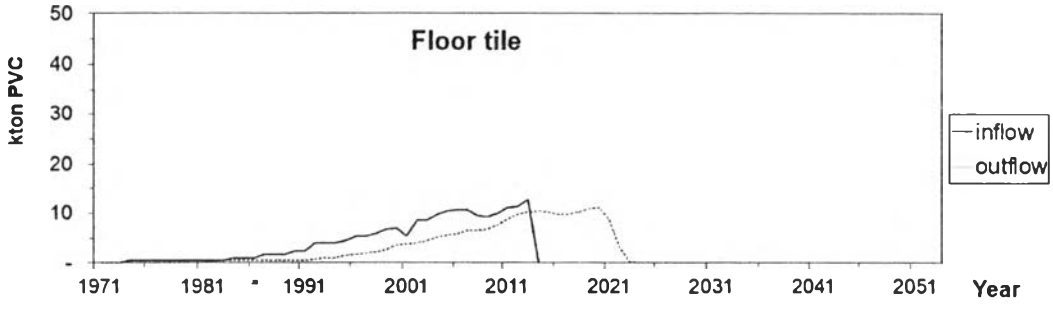
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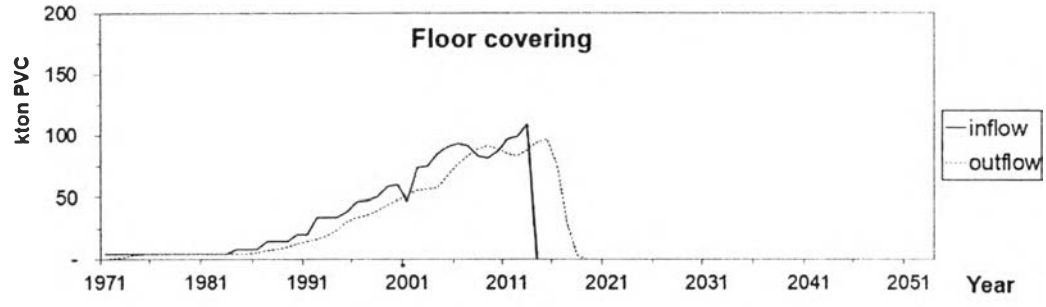

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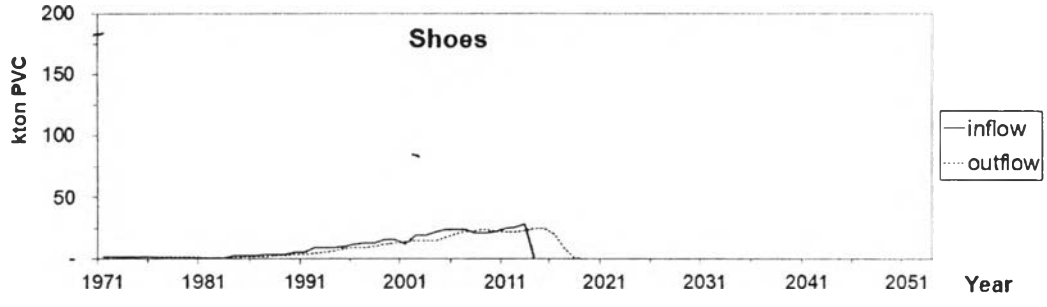

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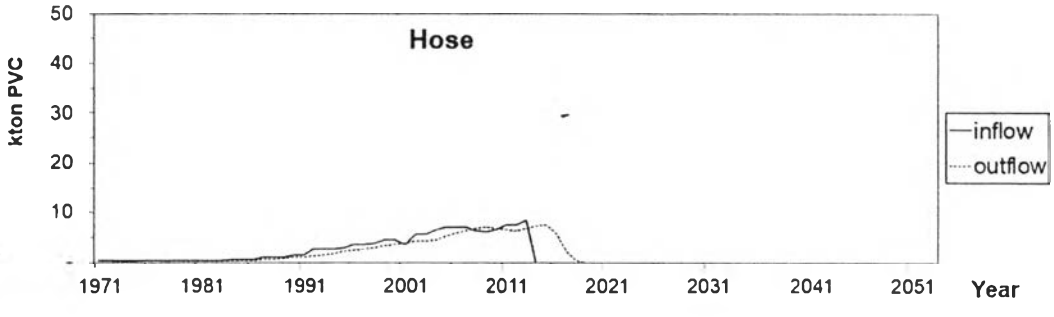


(g)

Figure 4.3 Annual outflow of multiple-year inputs of PVC products; a: pipe and fitting, b: profile, c: cable, d: floor tile, e: floor covering, f: shoes, and g: hose.

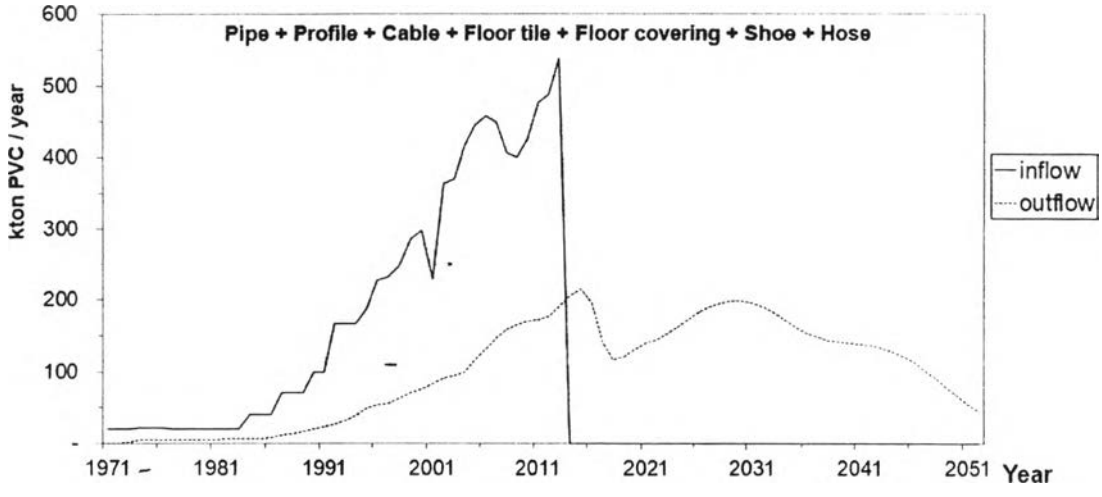


Figure 4.4 Annual waste outflow of multiple-year inputs of mixed PVC products.

Figure 4.4 shows the results of mixed PVC product inflow and outflow based on multiple-year inputs. The results indicated that PVC wastes are increasing every year depending on increasing of PVC product production and consumption. Moreover, the dynamic LC-MFA model can be used to calculate the amount of waste outflow from models in the past and present time. For example, in 2013 the mixed PVC product outflow was equal to 189,457 tons.

Table 4.1 Annual product outflows based on multiple-year inputs of mixed PVC products from 1971 to 2020 (ton)

year	Pipe and fitting	Profile	Cable	Floor tile	Floor covering	Shoes	Hose	Total
1971	-	-	-	-	-	-	-	-
1972	-	-	-	-	150	38	11	199
1973	-	-	-	-	1,181	303	90	1,574
1974	-	-	-	-	3,135	804	240	4,178
1975	-	-	-	-	4,166	1,068	318	5,553
1976	-	-	-	-	4,316	1,107	330	5,752
1977	-	-	-	-	4,316	1,107	330	5,752
1978	-	-	-	-	4,308	1,105	329	5,742
1979	-	-	-	-	4,257	1,092	325	5,674
1980	-	-	-	17	4,159	1,066	318	5,561
1981	-	4	10	136	4,107	1,053	314	5,625
1982	-	13	31	362	4,100	1,051	313	5,871
1983	-	30	74	480	4,100	1,051	313	6,049
1984	-	61	152	492	4,100	1,051	313	6,170
1985	-	114	285	480	4,242	1,088	324	6,534
1986	-	197	493	474	5,222	1,339	399	8,125
1987	-	317	791	474	7,078	1,815	541	11,015
1988	-	475	1,187	474	8,267	2,120	632	13,155
1989	-	669	1,671	474	9,853	2,527	753	15,947
1990	-	887	2,216	490	12,589	3,228	962	20,372
1991	9	1,113	2,781	603	14,242	3,652	1,089	23,489
1992	25	1,329	3,320	818	15,895	4,076	1,215	26,677
1993	51	1,517	3,791	955	19,102	4,898	1,460	31,775
1994	92	1,672	4,178	1,138	23,794	6,101	1,819	38,795
1995	156	1,790	4,473	1,454	30,158	7,733	2,305	48,070
1996	250	1,878	4,693	1,645	33,549	8,603	2,565	53,183
1997	383	1,956	4,886	1,836	35,285	9,048	2,697	56,091
1998	567	2,038	5,093	2,207	39,138	10,036	2,992	62,070
1999	809	2,149	5,368	2,749	44,192	11,332	3,378	69,977
2000	1,118	2,312	5,778	3,484	47,781	12,252	3,653	76,377
2001	1,496	2,548	6,366	3,875	51,674	13,250	3,950	83,159
2002	1,943	2,881	7,199	4,076	56,077	14,379	4,287	90,842
2003	2,451	3,326	8,309	4,521	56,672	14,532	4,332	94,143
2004	3,015	3,892	9,725	5,105	57,760	14,811	4,415	98,724
2005	3,615	4,591	11,472	5,519	67,626	17,341	5,170	115,334
2006	4,233	5,434	13,577	5,969	76,797	19,693	5,871	131,574
2007	4,863	6,423	16,048	6,478	83,837	21,498	6,409	145,555
2008	5,488	7,561	18,890	6,546	89,304	22,900	6,827	157,515
2009	6,102	8,848	22,106	6,672	91,440	23,447	6,990	165,605
2010	6,723	10,272	25,664	7,812	89,410	22,927	6,835	169,642
2011	7,361	11,798	29,479	8,871	85,042	21,807	6,501	170,859
2012	8,069	13,424	33,541	9,684	83,840	21,499	6,409	176,467
2013	8,873	15,111	37,755	10,316	88,082	22,586	6,733	189,457
2014	9,820	16,840	42,075	10,562	94,875	24,328	7,253	205,754
2015	10,970	18,596	46,462	10,328	97,235	24,933	7,433	215,956
2016	12,385	20,378	50,916	9,823	76,608	19,644	5,856	195,612
2017	14,111	22,196	55,459	9,685	29,586	7,586	2,262	140,885
2018	16,199	24,059	60,113	10,175	3,793	973	290	115,602
2019	18,700	25,989	64,934	10,959	-	-	-	120,582
2020	21,638	27,991	69,937	11,232	-	-	-	130,799

4.2 PVC Waste Management Scenarios

Based on the results from dynamic LC-MFA models, without mechanical recycling, and incineration processes, the PVC waste emission and accumulation into the environment after PVC product metabolism across the eight decades can be calculated as shown in Figure 4.5. LC-MFA models can predict that by the end of 2050 almost new PVC products from 1971 to 2013 will become PVC waste. Moreover, PVC waste accumulation will exceed eight million tons. Obviously, if we do not have a proper waste-management on PVC wastes, they will cause considerable quantity of wastes which is discharged into the environment in the coming decades. Moreover, it can have serious consequences on human life and environment. Therefore, appropriate measures, such as PVC end-of-life management and policy guides, should be implemented to reduce the PVC waste outflow.

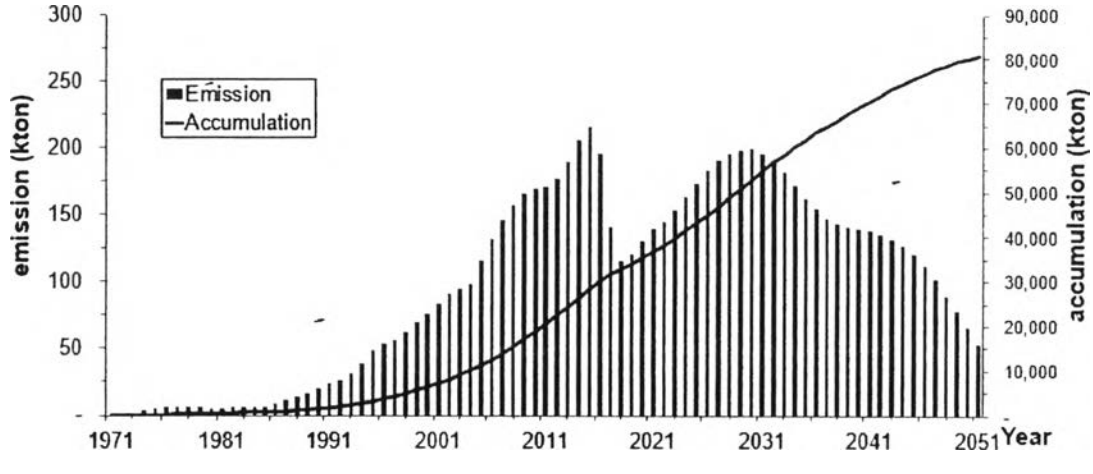


Figure 4.5 Annual emission and accumulation based on normal distribution of PVC products service life.

Since the PVC wastes are coming out to the post consumption phase, the effects of mechanical recycling and incineration on product metabolism of PVC should be taken into consideration in waste management scenarios. In this study, we created four different scenarios by varying the ratio of waste management technology (recycle, landfill, and incineration) as shown in Table 4.2 in order to simulate the results under the various situation of PVC waste management in Thailand. For the base case of end-of-life scenarios, we used the observation found in MTEC reported by Dr. Nudjarin Ramungul (2012).

Table 4.2 Four different scenarios of waste management technology (recycle, landfill, and incineration)

Scenarios	End-of-life treatment (%)		
	Mechanical recycle (H)	Landfill (G)	Incineration (S)
base case	30	67	3
a	50	50	0
b	70	30	0
c	90	10	0

According to the dynamic LC-MFA models, PVC waste emission to landfill and accumulation of wastes in each scenarios can be calculated during the period of eight decades from 1971 to 2050 as shown Figures 4.6 and 4.7. From all PVC waste management scenarios studied, the result indicated that scenario C which has 90 % recycle and 10% landfill show the lowest PVC waste emission and also in term of PVC waste accumulation.

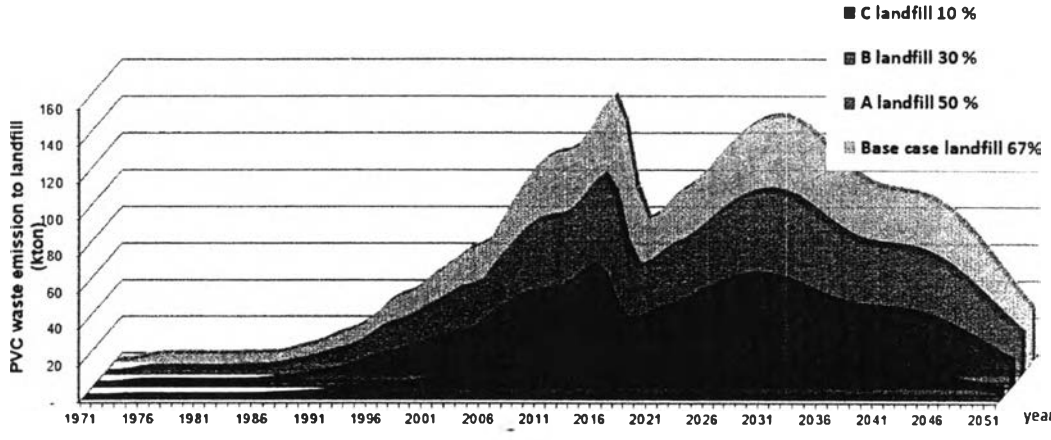


Figure 4.6 Amount of PVC waste emission to landfill on four waste management scenarios.

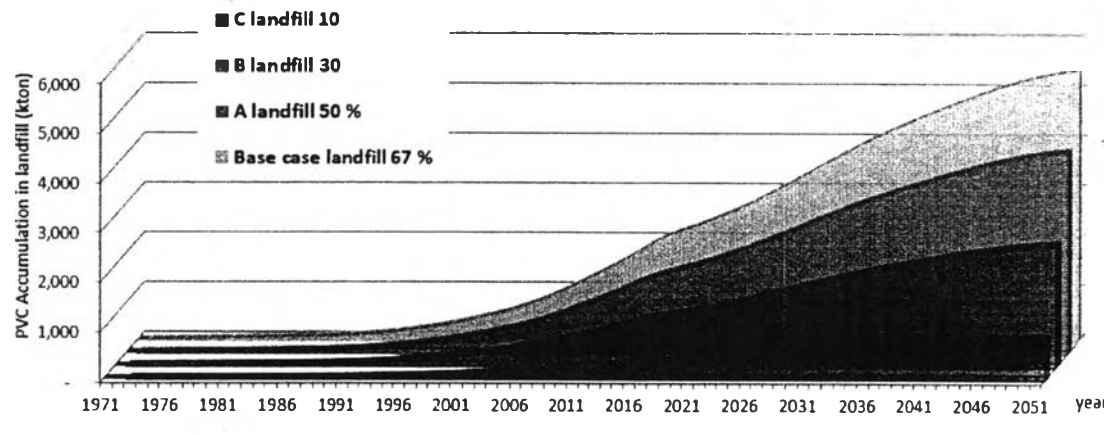


Figure 4.7 Amount of PVC waste accumulation on four waste management scenarios.

For mechanical recycling, we assumed that all PVC products were maintained in good condition during their usage, so they were manufactured into new products after processing by such processes as sorting, cleaning, granulation and melt regeneration. Mechanical recycling process still has an important role in PVC production phase because PVC waste can be recovered as a new material for PVC manufacturing which can help to solve problems on lacking of PVC supply in

production phase and reduce environmental impact. Therefore, mechanical recycling had significant effects on relieving the environmental problems caused by PVC wastes. According to the results of LC-MFA model in Figures 4.8 and 4.9, Scenario C also shows the highest amount of PVC recycle and the accumulation of PVC recycle in PVC metabolism.

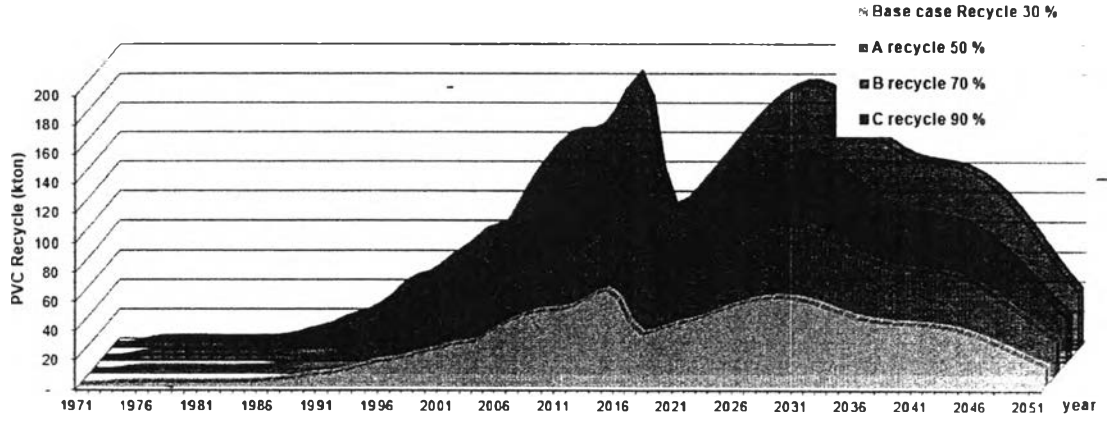


Figure 4.8 Amount of PVC recycling which can be used as a new material on four waste management scenarios.

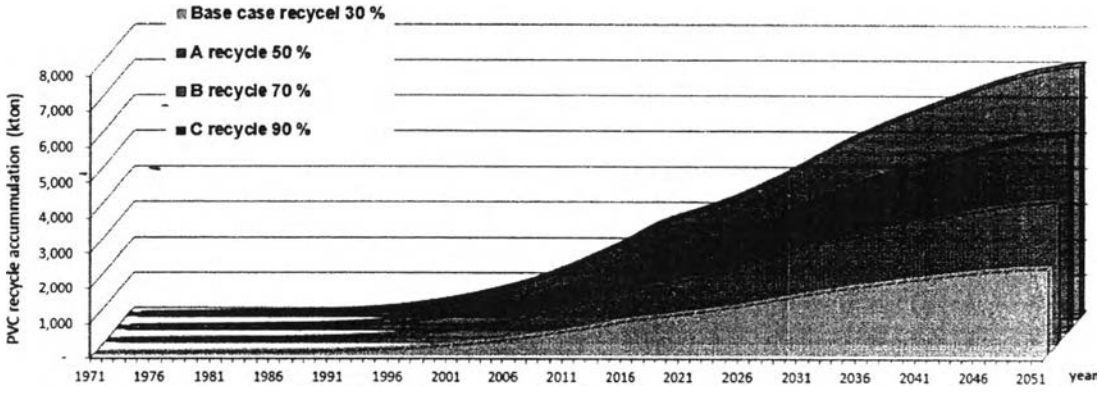


Figure 4.9 Amount of PVC recycle accumulation on four waste management scenarios.

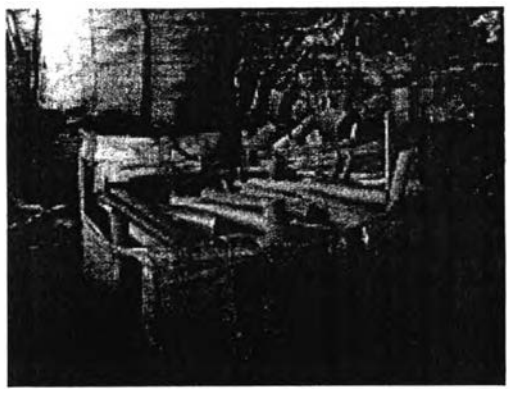
4.3 Actual Results from Site Visits

4.3.1 Recycle shop

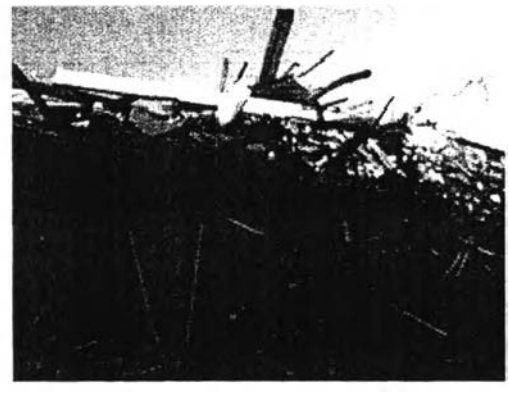
Based on site visits to a major recycle shop in Bangkok: Amorn Recycle shop where all kinds of PVC wastes such as pipe and fitting, profile, cable, floor covering, shoes, hose etc. as shown in Figure 4.10 are collected from several places around the country. At this recycle shop PVC waste are categorized by type of products, and then the PVC waste are cut into small piece. The cut PVC wastes are cleaned in the rotary washer. The cleaned PVC are then packed in a big plastic bag weighted about 1 ton each before being sent to other factory. It is believed that at present, this shop cover around 40% of PVC recycle being circulated in Thailand. The data of overall PVC recycle in Thailand can be estimated by extrapolation from the amount from this recycle shop as shown in Table 4.3. The total PVC recycle circulating in 2013 is approximately 21,408 tons

Table 4.3 Results of the site visit at Amorn recycle shop

Applications	Actual data (ton)	Estimated total amount of PVC recycle (ton)
Pipe & Fitting	3,383	8,457.5
Profile	84	210
Cable	907	2,267.5
Floor tile	0	0
Floor covering	935	2,337.5
Shoes	1,550	3,875
Hose	1,704	4,260
Total	8,563	21,407.5



Pipe and fitting



Profile

Cable

Floor covering

Shoes

Hose

Figure 4.10 PVC recycle found in recycle shop.

4.3.2. Landfill sites

According to site visits at landfill sites, we visited many landfill sites in Thailand (Figure 4.13) covering almost regions in Thailand (Central, North, Northeast, and south) and different sizes (large, medium, and small size) of waste producers. The samples from quartering method were sorted into 8 types: organic waste, plastic waste, paper, fabric, aluminium, glass, shoes, and hazardous waste as picture shown in Table 4.4. The results from landfill sites in each areas in Thailand are shown in Table 4.5 and the compositions of municipal solid waste are shown in Figures 4.14 and 4.15. Based on the results from landfill sites, many types of waste such as organic waste, plastic waste, paper, fabric, aluminium, and glass were found commonly. However, some of target PVC products such as pipe, profile, and floor tile have not been found so far. PVC cable and hose have been found, but they have a relatively small amount at landfill site as shown in Table 4.13.

Figure 4.13 Research team and workers at landfill site visits.

Table 4.4 Eight categories of municipal solid waste in this study

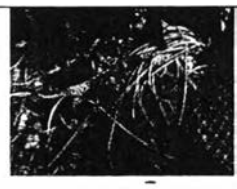
Pictures	Description
	Organic waste food, vegetable, wood
	Plastic waste plastic shopping bag, packaging, toy, other plastic applications
	Paper paper, newspaper, milk packaging, diapers, sanitary napkin
	Aluminium and metal can, tin, spoon, wire
	Fabric cloth, clothing, fabric, rag, tab
	Glass mixed glasses from many products
	Mixed foot wear slipper, leather shoes, sport shoes
	Hazardous waste light bulb

Table 4.5 Results from landfill site visits

	Regions					Average	Amount of waste (ton)
	Central	West	Northeast	North	South		
Organic waste	60.7541%	60.9761%	55.7805%	61.4671%	48.7007%	57.5357%	9,193,825
Plastic Shopping bag	15.5032%	6.8025%	14.8790%	6.9817%	7.6719%	10.3676%	1,656,681
Other plastic products	3.2224%	14.1249%	10.2442%	11.9512%	14.4257%	10.7937%	1,724,756
Paper	9.9955%	10.1189%	8.4531%	7.4761%	13.1088%	9.8305%	1,570,845
Fabric	4.8767%	2.0679%	2.4592%	2.8225%	3.5889%	3.1630%	505,432
Glass	3.2488%	2.7041%	2.8307%	5.1669%	7.3276%	4.2556%	680,022
Aluminium and metal	0.6933%	1.0415%	1.0964%	1.1625%	1.1893%	1.0366%	165,639
Plastic Bottle	1.2549%	1.9855%	3.1457%	1.7754%	1.5244%	1.9372%	309,551
Hazardous waste	0.0000%	0.0000%	0.0000%	0.0000%	0.2435%	0.0487%	7,781
Pipe and fitting	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	-
Profile	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	-
Cable	0.0000%	0.0000%	0.0374%	0.0000%	0.0078%	0.0090%	1,443
Floor tile	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	-
Floor covering	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	-
Foot wear	0.4510%	0.1786%	1.0739%	1.1967%	2.1530%	1.0106%	161,494
Hose	0.0000%	0.0000%	0.0000%	0.0000%	0.0584%	0.0117%	1,865
Total	**100.0000%**	**100.0000%**	**100.0000%**	**100.0000%**	**100.0000%**	**100.0000%**	**15,979,335***

*Total amount MSW in 2012 is 15,979,335 tons reported by PDC annual report 2011

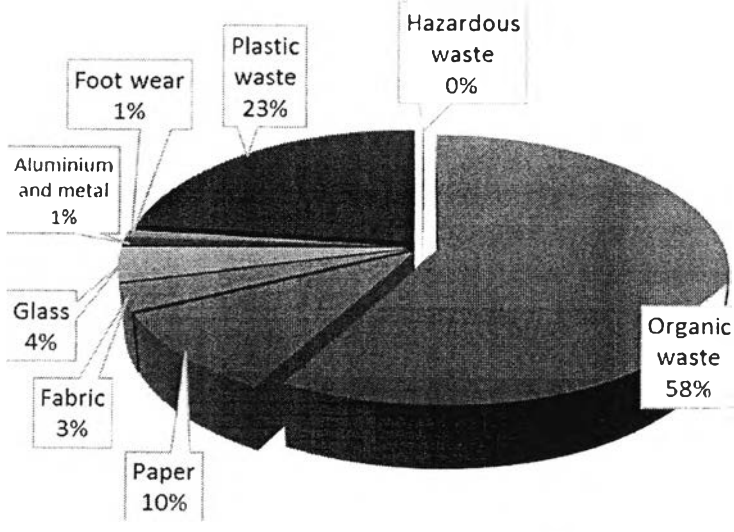


Figure 4.14 The overview municipal solid waste composition in Thailand from this study.

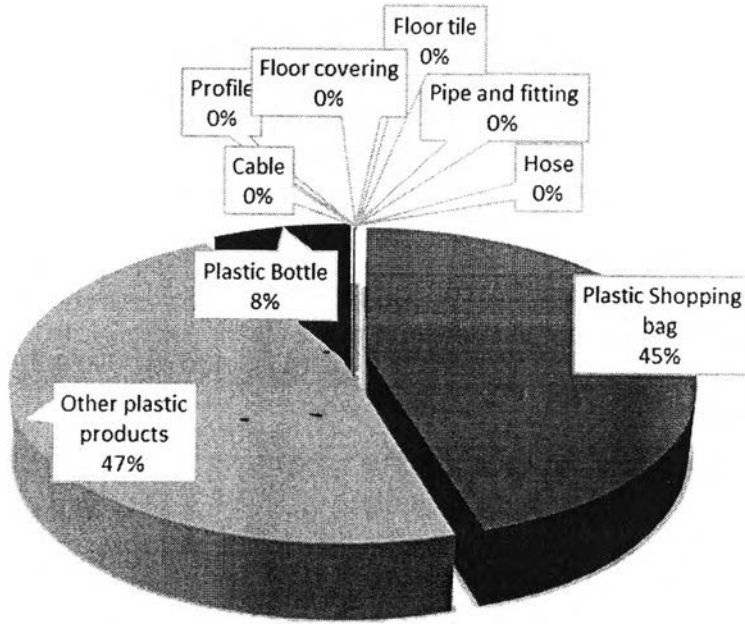


Figure 4.15 The proportion of plastic applications in plastic waste in municipal solid waste.

Table 4.6 Possibility find of PVC target products in landfill site visits

PVC application	Possibility find PVC target products	Percentage of PVC waste	Amount of PVC waste per year (ton)
Pipe & Fitting	Not found	-	-
Profile	Not found	-	-
Cable	Rare	0.0090%	1,443
Floor tile	Not found	-	-
Floor covering	Not found	-	-
Shoes*	Occasional	1.0106%	161,494
Hose	Rare	0.0117%	1,865

*Shoes is a composite shoes including fabric, rubber, and other plastics.

4.4 Material Flow Analysis and Model Tuning

Based on LC-MFA model results in 2013 and actual site visit results in 2013, we can see that PVC waste outflow from model is equal to 189,457 tons. However, when we visited at landfill and incineration sites, the target PVC products were rarely found at sites. In addition, at recycle shop the target PVC products were found around 21,407 tons.

We used data from model results and data from actual site visit to do material balance and find tuning model. From material balance as shown in Figure 4.16 L(t) or PVC waste out-flow from model should be equal to the summation of R(t) amount of PVC recycle, amount of PVC waste go to landfill, and amount of PVC waste go to incineration process. However, in case of PVC products, we do not treat the PVC household waste and PVC construction waste with incineration, so outflow form model or L(t) should be equal to the summation of R(t) PVC recycle and G(t) PVC go to landfill.

After doing material balance as, we found that up to 95% of pipe & fitting are being recycled which is the highest followed by hose (63% recycled) and shoes (almost 20%). Other products still show low recycling rate which may be due to lack

of application for recycled wastes, etc. as shown in Table 4.7. However, after doing material balance, there are some mismatch amount between the results from LC-MFA model and the results from actual site visits. There are several explanations for mismatch amount as follow:

- Average service lifetime and lifetime span used in this study may not be the same as the real situation.
- Some unused PVC products were not removed out of place as wastes after finishing their service life.
- Some PVC wastes were removed out with construction wastes and remained in the construction wastes dump sites

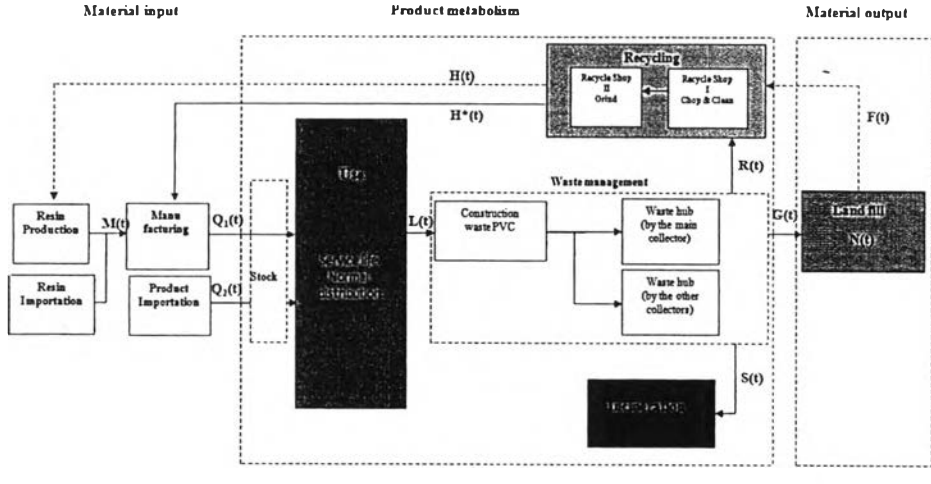


Figure 4.16 LC-MFA model of PVC construction products.

Table 4.7 Results of material balance between the results from model and the results from actual site visit

Products	Outflow from model (ton) (L(t))	Recycle (ton) (R(t))	Landfill (ton) (G(t))	Mismatch amount (ton)
Pipe and Fitting	8,873	8,458 (95.3%)	0 (0.0%)	415 (4.7%)
Profile	15,111	210 (1.4%)	0 (0.0%)	14,901 (98.6%)
Cable	37,755	2,267 (6.0%)	1,804 (4.8%)	33,684 (89.2%)
Floor tile	10,316	0 (0.0%)	0 (0.0%)	10,316 (100.0%)
Floor covering	88,082	2,337 (2.7%)	0 (0.0%)	85,745 (97.4%)
Shoes	22,586	3,875 (17.16%)	161,494 (715.0)	-142,783 (-632.2%)
Hose	6,733	4,260 (63.3%)	2,331 (34.6%)	142 (2.11%)