Fluorocarbon Refrigerant Management in Selected ASEAN Countries: A case study on refrigerant leakage and recovery potential rate

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ABSTRACT

In most ASEAN countries the focus of managing fluorinated gases is still lack compared to other greenhouse gases (GHGs). Even though fluorinated gases share small amount of total greenhouse gases (GHGs) emission, its potent and referred to as high global warming potential (GWP) gases. As a basis for discussion, this study analysed trend of fluorocarbon refrigerant management at regional level by cross-country analysis in Malaysia compared to neighbouring Indonesia, Thailand and Vietnam. Focus group discussion and expert interview were conducted with selected stakeholders. For case study, research scope assessing condition at consumption level by monitoring refrigerant leakage rate during operation. The leakage rate and greenhouse effect was determined by experimental evaluation on the Total Equivalent Warming Impact (TEWI) for split-unit air conditioning systems. As on-site disposal handling option, estimation for recovery potential rate was also conducted. Sample of R123 (HCFC) was collected from a chiller unit and undergo reclamation process for reuse purpose hence reducing the possibilities of improper wastage and leakage. At regional level, it can be concluded that these countries shared common issue of low awareness level, no regulation imposed, less cross ministerial among regulator, no proper collection and disposal facilities, lack financial support as well as cost competitiveness. Meanwhile, from a case study shown that total direct and indirect emission is predicted to release 350,473.52 t eq CO_2/year. From the impurity test, results indicated that 79.21% of R123 sample was reclaimable, which could reduce the negative impact on the environment if being recovered accordingly.

Keywords: Ozone Depletion Substances (ODS), Global Warming Potential (GWP), Refrigerant Leakage, Direct and Indirect Carbon Released, Cross-Country Analysis

Introduction

Fluorinated gases chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) is a key role in ozone layer depletion and global warming (Wang, C et al., 2014). This compound act as ozone depleting substance (ODS) due to the releasing free chlorine atom into atmosphere and initiate catalytic cycles (Wu et al., 2013). Nowadays, HCFC-22 (R22) which act as substituted of CFC, is widely use as refrigerant in air conditioners, industrial and commercial refrigeration, fire extinguishing, manufacturing of foams and cleaning solvents (Aggarwal et al., 2013). However, this refrigerant contained an ozone depletion potential (ODP) 0.04 and also global warming potential (GWP) 1780 for 100 years (Li et al., 2016) hence highly important to manage it in sound manner. The abundance of fluorocarbons in atmosphere are control under the Montreal Protocol through phasing out ozone depleting substances (ODS) that caused CFCs usage were banned, HCFCs consumption being control and substitution cooling refrigerants for hydrofluorocarbon (HFCs) as well as natural gases. The Montreal Protocol has been hailed as successful environmental convention that led to regeneration of ozone layer and resulted significant reduction in GHGs emission. Thus moving forward, important future milestones are the 10% reduction of HCFC consumption in 2015 and the 35% reduction target in 2020. The GWP of greenhouse gases (GHG) that have a very long atmospheric lifetime is the index describing its relative ability to collect radiant energy in comparison to CO_2, ozone depletion potential (ODP) will be zero if the refrigerants are selected with reduced GWP (Sarbu, 2014). Therefore, in order to determine the suitability of refrigerant, the estimation, and calculation of the relative GHG emissions are considered to be important and can serve to be an as important reference (Zhao et al., 2015).

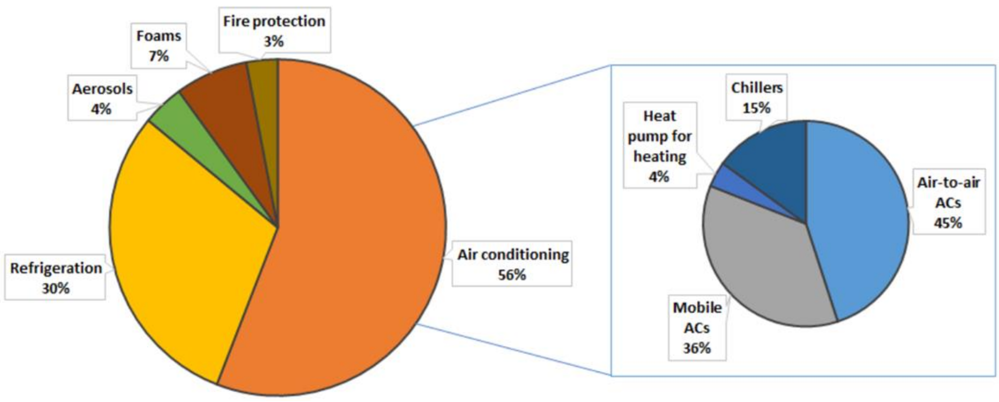

Figure 1 Market using HFCs, % of tonnes CO_2e in 2012 (UNEP Ozone Secretariat., 2015)

Fluorinated gases are very heterogeneous category with large difference in growth rates and often very large uncertainties in emission thus lead to share of fluorinated gases emission is about 3% globally, and show the highest growth rate in 2016 (3.8%) with largest sub-categories are HFC-134a from refrigeration and air conditioning (about 19%), HFC-125 and HFC-143a from consumption (17% and 19%) and HFC-23 which is by-product of the production of HCFC-22 (19%) (J.G.J Olivier et al., 2017). Main end uses of HFCs shown in Figure 1. High domination usage in air conditioning sector (56%), where 45% of global HFC emission in 2012 were dominated by air-to-air air conditioning system. While in developing countries demand for refrigerant and blowing agents is expected to increase three times by

2030 due to economic growth (Zeiger et al., 2014, The Linde Group, 2015). Table 1 shows that summarizes on the demands of air conditioners in Malaysia, Indonesia, Thailand and Vietnam. All of these countries are referred under A5 Parties - Group 1 subjected under Kigali Amendment to the Montreal Protocol. As a sign of supporting the implementation of HPMPs at the national level which to accelerate the HCFCs to be phase-out, the country under the A5 Parties - Group 1 received assistance from UN Environment, the United Nations Development Programme (UNDP), the United Nations Industrial Development Organization (UNIDO), the World Bank, and the Multilateral Fund (MLF) in various areas.

Table 1: Details of room AC demand and refrigerant used in 2015 (Shah *et al.*, 2017)

Country	Room AC Demand (thousand units)		Refrigerant
	2010	2015	
World Total	73,420	79,389	R-22 dominant (Other Asia Total)
Malaysia	751	789	R-22 dominant, R-32 (starting)
Indonesia	1493	2109	R-22, R-410A, R-32 (~33%)
Thailand	957	1268	R-22, R-32 (~50%)
Vietnam	670	1546	R-22 (~60%), R-32 (~20%)

In Malaysia, consumption of HCFCs are expected to be completely phase-out by 2030 as required by the Malaysian Government (DOE, 2012). An outlines the overall framework and strategies of implementation from the national HPMP has set up to achieve the objective of the plan and the plan details actions to be taken to phase-out the use of HCFCs in all sectors, namely in refrigeration, foam, air conditioning, fire-fighting and solvents (Vitooraporn, 2009). The production and consumption of HCFCs are under the Government plan to be freeze from January 1, 2013 to achieve a 10 percent gas reduction by 2015 with zero consumption in CFCs by 2010 (DOE, 2012). To provide technical assistance to locally manufacturing companies has been viewed as a necessity by the Government of Malaysia to ensure that they are adequately supported in managing HCFC and non-HCFC technologies (DOE, 2018a). Meanwhile in Indonesia, to use R-32 (HFC) as an alternative to R-22 (HCFC) is a decision made by the Government of Indonesia with the support from United Nations Development Program (UNDP), the government also plans to promote the use of R-32 (HFC) for refrigerant conversion (Harman and A. Hamarung, 2017). Referring to the Indonesia Government’s Plan, a policy of phasing out R-22 (HCFC) in air-conditioning and refrigeration by the year 2015 will see Indonesia completely convert to R-32 (HFC) by the year 2015. As for this reason, regulatory measures are being strategies. Approach taken by Thailand lead by The Royal Thai Government by Department of Industrial Work (DIW) has establish Control ODSs as Hazardous Substance and set up ODS Phase-out guidelines for industrial sectors to comply with the Montreal Protocol. DIW has announced the guideline for importing HCFC in the year 2012 by stating that any import activity of R-22 (HCFC) will be controlled in the year 2013-2014. However, in Vietnam, no regulation on air conditioners using HCFCs has been implemented yet, and starting with the Decree 80/2006 in 2006 until various Decrees in 2011, Vietnam has put in place a legal framework to promote energy efficiency with mandatory minimum energy performance standards (MEPS) MEPS for residential ACs.

There is potential in using traceable collection of refrigerants in the process of reducing resources consumption which would in turn reduces the environmental impacts and results due to climate change. Hence this would also allow us to handle used refrigerant effectively without harming the environment. Many research has focused on the rapidly increasing GHG emissions resulting from the leakage of refrigerants globally (Yuan et al., 2018). Leakage is essentially defined as any unwanted or unwanted opening in any closed medium that contains some fluid and allows the opening to escape (Mehboob et al., 2018). The leakage happens mainly at the point of joints, welded or brazed joints and cracked surfaces (Elbel and Lawrence, 2018).

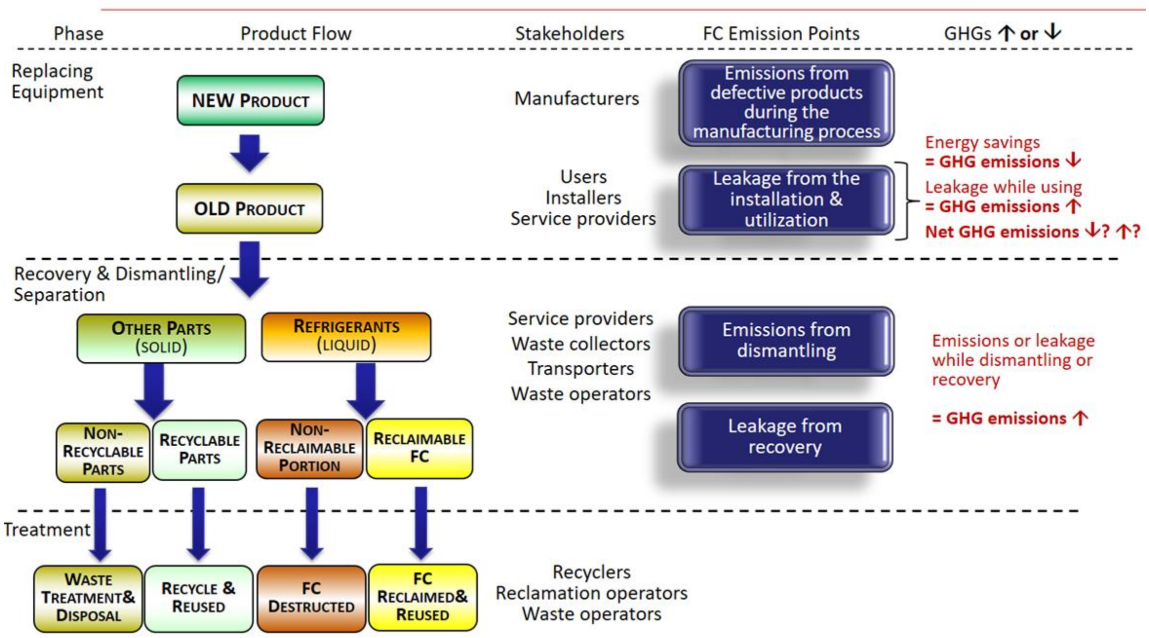

Figure 2: Controlling refrigerant leakage by phases and GHG effects

Leakage also has a significant environmental impact as shown in Figure 2. Refrigerants contribute to GHG emission during various product flow handling, maintenance and disposal. There are two key environmental impact areas which is direct leakage means emission into the atmosphere of refrigerant gasses that can cause ozone depletion and contribute to global warming; and indirect leakage when refrigeration and air conditioning systems consume energy that increases emissions of CO_2 and contributes to global warming (The Linde Group, 2019). Refrigerant losses contribute to global warming both directly and indirectly through inefficient system operation, increased energy consumption and greenhouse gas emissions, and significantly increased maintenance costs (Tassou and Grace, 2005).

The method of handling fluorocarbons (FCs) substance is also crucial because improper handling will certainly lead to leakage, breakdown of ACs and release of carbon into the atmosphere. The proper handling method includes the collection of disposed e-waste, which contains FCs such as refrigerator, chiller system, vending machine, including the refrigerant extraction process from the air-conditioning system. Traditionally, e-waste is collected and being stored in a facility to be dismantled and precious metal is extracted from the waste. This process, however, does not include proper extraction of FCs and are usually being released by the contractor into the atmosphere. The extracted FCs are stored in a container by some contractors and being left without proper management. The container would decay in the long run due to rust formation and will cause leakage. Through reclamation, the substance can be reused onto the chiller system, hence reducing the possibilities of improper wastage and leakage (UNEP, 2015). This can minimize direct and indirect emissions during the disposal of refrigerants and also the production of new refrigerants, thus reducing energy usage during the production, which can slightly improve energy consumption during recycling and disposal operations (Zhao *et al.*, 2015).

2. Materials and Methods

2.1 Fluorocarbon refrigerant management at regional level

The focus of the initial discussion was to obtain an overview of the common practices and availability of the data needed for this study. The individual approach and focus group discussion (FGD) practices was carried out in 2016, in series of visit from August to November 2016. The objectives of this study and way forward are then being explained to all stakeholders. This includes measures to accelerate both the technology diffusion of energy-efficient equipment using low-GWP/natural refrigerants and proper treatment system of FCs from used refrigerants prior to disposal including regulation required to comply and future plans in accordance to each country plan and requirements. All these stakeholders are an expert group which is particularly good and expert with knowledge related to this research, as summarised in Table 2. This method used in this studies was interviewing and documents review to ensure respondents understand on related issues and it provides better access for exploring sensitive issues.

Table 2: Respondents from cross-country analysis

Stakeholders	**Numbers**	**Details**
Government Officers	19 (Departments/Offices)	National ozone units and their supervisory authorities, energy efficiency-related departments, waste regulators, standards department, training institute

Academia	8 Universities	Specialists in policies and technologies for refrigerants and wastes
Association & Institutes	14 entities	Equipment manufacturers, servicing/maintenance technicians, waste operators, green buildings
Private Companies	11 companies	Equipment manufacturers, gas traders, waste handlers, recycling and transportation companies, FCs destruction (industrial waste treatment) operators
Others	5 entities	UNEP, UNDP, JICA

2.2 Direct and indirect emission during operation at consumption level

As case study, data collection is being carried out in one of Higher Education Institutes (HEIs) in Malaysia, Universiti Teknologi Malaysia. Main secondary data was provided by Universiti Teknologi Malaysia Office of Asset and Development (UTM OAD) for the year 2016. UTM OAD appoints contractors in order to provide air-conditioning systems and refrigerants for refilling existing air-conditioning system. To cover 1,177 hectares of UTM, UTM OAD has divided four zone and divided each zone with a different contractor responsible for doing work and recording maintenance work. In addition, contractors who have been appointed by UTM are responsible to install air-conditioning unit, change or transfer air-conditioning, and recharge refrigerant into air-conditioning. Therefore, maintenance of monthly work records is vital for this study because the intake reflects the amount of refrigerant being purchased and also used. Related data was collected focused on the usage of R-22 (HCFC) and R-410A (HFC) refrigerants on four different maintenance zoning areas inside the campus. Data amount of refrigerant purchased and recharged into the split unit air-conditioning system were obtained from appointed contractors to refill existing air-conditioning system. Accordingly, basic inventory information needed is a type of air-conditioning, the model of each air-conditioning, capacity, quantity, air-conditioning life span and type of refrigerant used. Figure 3 shows complete data required, it makes it easier to take the next step of direct and indirect carbon emission calculations.

Total Equivalent Warming Impact (TEWI) is a standardised method of calculating global warming impact of refrigeration equipment and system that focusing on the total related emissions of greenhouse gases during the operation of the equipment and disposal of the operating fluids at end-of-life. This method of calculating TEWI is dedicated for new air conditioning system and stationary refrigeration systems that operate using vapour compression principles and powered using main electricity connected to the grid. The main aim of this method is to provide predictive estimation for TEWI values on new systems. However, sensitivity analysis is recommended to calculate lower and upper threshold TEWI values. Method of calculating TEWI is provided as in Equation 1.

NO	BLOCK	TYPE	MODEL	CAPACITY	QUANTITY	REFRIGERANT	AC Lifespan	ANNUAL ENERGY CONS
1		SPLIT	TCF	5	2	R22	10	21774.44
2		SPLIT	TCF	3	1	R22	10	6532.332
3		SPLIT	TOPAIRE	1.5	1	R22	10	3266.166
4		SPLIT	ACSON	2	8	R22	10	34839.104
5	D01	SPLIT	YORK	2.5	3	R22	10	16330.83
6		SPLIT	TCF	2.5	1	R22	10	5443.61
7		SPLIT	YORK	5	1	R22	10	10887.22
8		SPLIT	YORK	2	3	R22	10	13064.664
9		SPLIT	MITSUBISHI	2.5	3	R22	10	16330.83
10		SPLIT	TCF	3	2	R22	10	13064.664
11		SPLIT	ACSON	3	1	R22	10	6532.332
12		SPLIT	YORK	2	7	R22	10	30484.216
13		SPLIT	TOPAIRE	1.5	1	R22	10	3266.166
14		SPLIT	YORK	5	5	R22	10	54436.1
15		SPLIT	TCE	5	1	R22	10	10887.22
16	D02	SPLIT	YORK	3.5	1	R22	10	7621.054
17		SPLIT	YORK	2.5	4	R22	10	21774.44
18		SPLIT	YORK	3	1	R22	10	6532.332
19		SPLIT	YORK	4	3	R22	10	26129.328
20		SPLIT		2	1	R22	10	4354.888
21		SPLIT	YORK	1	1	R22	10	2177.444
22		SPLIT	YORK	1.5	1	R22	10	3266.166

Figure 3: Inventory data for direct and indirect emission

2.2.1 Direct emission

The is four main types of direct emissions from air-conditioning system where it is due to losses during plant service and maintenance, gradual leaks during normal operation, catastrophic losses during normal operation and losses at the end of plant life. Global Warming Potential (GWP) values for refrigerant used was adapted from the assessment report has been published by The Intergovernmental Panel on Climate Change (IPCC) that review current climate science and assess impacts on the human and natural landscape published in 2013. Table 3, includes the 100-year time horizon GWP relative to CO_2. This table is adapted from the IPCC. The AR5 values are the most recent, but other values are also listed because sometimes used for inventory and reporting purposes (Drouet et al., 2015).

The class of equipment, refrigerant type, equipment design, operating condition and workmanship during installation vary the annual leak rates (Andersen et al., 2013). The annual leak rate is considered as catastrophic losses amortized over life of the equipment, the sum of gradual leakage and losses during service and maintenance expressed as a percentage of initial charge per annum (AIRAH, 2012). Annual emission rates are estimated between 7% and 12% in most of the A5 countries based on UNEP, the Technology and Economic Assessment Panel (TEAP) throughout report in 2010. The original refrigerant charge of the system. For stable unit operation, the charge existing in the refrigeration system is fulfilling the required charge for stable operation for unit and all possible operating conditions. The minimum charge required for the refrigeration system is not only depending on the design of the unit, but also on the operating conditions (IPCC, 2014). The operating system of life for refrigerant is the useful life expectancy for a refrigeration (capital) equipment. The period of use in service is consider a product's system operating life which in this case focusing on a refrigeration system. It is constantly defined as the period if any particular product being used from the point of purchase or assembled to the point of discard.

$$\text{TEWI} = \text{GWP (direct; refrigerant leaks incl. EOL)} + \text{GWP (indirect; operation)} \quad \text{Equation 1}$$

$$= (GWP \times m \times L_{annual} \times n) + GWP \times m \times (1 - \alpha_{recovery})) + (E_{annual} \times \beta \times n)$$

Where:

GWP = Global Warming Potential of refrigerant, relative to CO_2 (GWP CO_2 = 1)

L_{annual} = Leakage rate p.a. (Units: kg)

n = System operating life (Units: years)

m = Refrigerant charge (Units: kg)

$\alpha_{recovery}$ = Recovery/recycling factor from 0 to 1

E_{annual} = Energy consumption per year (Units: kWh p.a.)

β = Indirect emission factor (Units: kg CO_2 per kWh)

Table 3: Global Warming Potential (GWP) values relative to CO_2

Substance	**GWP Values for 100-year time horizon**			
	Chemical Formula	**Second Assessment Report (SAR)**	**Fourth Assessment Report (AR4)**	**Fifth Assessment Report (AR5)**
Carbon dioxide	CO_2	1	1	1
Methane	CH_4	21	25	28
HCFC- 22 (R-22)	$CHCLF_2$	1500	1810	1760
HFC-32 (R-32)	CH_2F_2	650	675	677

*AR – Assessment Report (IPCC, 2013)

2.2.2 Indirect Emission

The emission factor of CO_2 or sometimes referred to as an indirect emission is referred to as average emission intensity of total electric sector generation for the region. The quantity of carbon release per kWh of electricity supplied is based on the fuel mix in electric generation. If it is generated from a coal fired power station, the figure would be higher compared to gas-fired stations, hydroelectric, wind power or solar. For the calculation of data indirect emission, GWP, refrigerant charge, recovery / recycling factor, energy consumption per year, indirect emission factor, and system operating life are required. Removal of refrigerant from a system and its storage in an external container. Refrigerant recovery refers to the process of extracting used refrigerant from a refrigeration system and undergo specific process to enable the refrigerant to be useable hence allowing the recovered refrigerant to be reusable by inserting back into the same refrigerating system. In specific, the term refrigerant recovery rates bring the definition of the percentage of refrigerant that could be recovered from a system which has not been contaminated after undergoing the recovery process. According to IPCC, the best practice guidelines for refrigerant recovery rate from a system with a refrigerant charge greater than 100 kg would be expected to be 90% to 95% of the remaining charge, and around 70% for equipment with smaller charges. Guideline recommends the use of a refrigerant recovery rate of 70% of the original charge for systems with a refrigerant charge. Energy consumption of the system per annum refer to the amount of energy consumption by a certain system to ensure that the system is able to function efficiently throughout a year. This energy focuses on electrical energy as it is the main source of energy for any refrigeration system. The indirect emission factor of CO_2 is defined as the mass of CO_2 emitted by the power generation per kWh of electrical power supplied to the refrigeration installation that losses of efficiency in generation and distribution (Units: kg CO_2/kWh). For Malaysia, the global average emission factor for grid electricity is around 0.73 kg CO_2/kWh (H. Clark, 2013).

2.2.3 Leakage rate

Equation 2 is the equation to identify refrigerant leak rates. This equation was introduced by the United States Environmental Protection Agency (US EPA) in its National Management program. This equation in another name is called a retrospective approach method. Based on US EPA, this equation contributed to all the cooling additions over the last 365 days or since the last successful verification test of success shows that all identified leakages have been successfully repaired (if less than 365 days).

$$\text{Leak rate (\%/year)} = \frac{\text{Weight of refrigerant added over past 365 days}}{\text{Weight of refrigerant in full charge}} \times 100\% \qquad \text{Equation 2}$$

2.3 Recovery potential rate during on site disposal

Sample of R-123 (HCFC) was extracted and stored in drums as it existed in the form of liquid state and was transported to the reclamation centre company certified by DOE in order to carry out the process of reclamation. A receiving tank will collect the reclaimed sample as and it will undergo another in-processing or final quality and lab testing. After testing the sample will be classified as a reclaimed refrigerant to be reused into the chiller system. Once the recovered refrigerant is transported to the centre, the refrigerant undergoes testing using lab tests for the presence of impurities.

2.3.1 Reclamation process

Chemical analysis will be required to determine that appropriate product specification are met. The reclamation process is involving the recovery and substantial reprocessing of refrigerant to virgin specifications as standardised by industry because specialised machinery is required because reclamation does not occur on-site (AHRI, 2016). The contamination includes the presence of solids, high boiling residues, moisture, acidity, chlorine and non-condensable gases. There is an estimated loss of recoverable gases whereby it is estimated only 70% of the recovered gas can be regenerated by filtering and distillation. This is due to the 30% degradation of fluid characteristic that is not allowable for reuse. It is also proving that 1% of the fluid is emitted to the atmosphere during the reclamation procedure, 1% is comprised of impurities (Cascini et al., 2016)

Table 4: The refrigerant testing according to AHRI Standard 700

No.	Item for analysis	Specification
1	Water content, ppm by weight	20 ppm max
2	High boiling point residue, wt %	0.01% max
3	Impurities, wt%	0.5% max
4	Acidity, ppm	1 ppm max
5	Chloride	No visible turbidity
6	Particulate /solids	Visually clean

The used refrigerants should be tested as to verify that it has attained AHRI 700 or ISO 12810, or equivalent specification prior to resale as required by the U.S. Environmental Protection Agency (EPA) (Damodaran and Donahue, 2010). The specification listed in Table 4 is compulsory under AHRI 700 standards and it must be taken into account to determine if the sample could be reclaimable. Non-reclaimable refrigerants must be disposed in sustainable way for environment and in accordance with the applicable regulations (Baxter et al., 2016).

3. Results & Discussion

3.1 Fluorocarbon refrigerant management at regional level

The data collected concluded that there are seven main common issues among all four assessed countries Malaysia, Indonesia, Thailand and Vietnam. Level of awareness among users and relevant sectors are still very low. Households, commercial and industrial users are not aware of the importance of proper treatment of FCs. Energy sector people are not aware that GHG emission reduction achieved from energy savings may become net GHG emissions with FC leakage; while very few companies treat their used FCs due to lack of regulations specifically requiring the proper management of the FCS. There is also no regulation yet to be introduced to mandate the FC recovery from used equipment contained FCs in all four countries even though they have already introduced or to be put into effect a ban for manufacturing or importing new equipment using R22 refrigerant or importing R22 refrigerant with an exception for serving existing equipment. Another important point of governance is less cross-ministerial and departmental discussion among regulators that can be a platform to raise the issue of proper treatment of FCs. At operation level, similar trend was observed in collection and transportation issues of FCs for used equipment of home appliances. Commercial and industrial sectors can voluntarily request their servicing/maintenance companies to collect the refrigerants, but not household users. For the household sector, managing and monitoring collection and proper treatment of FCs become challenging due to the presence of informal sector. These countries also facing difficulty in reclaiming recovered FCs due to illegal mixing of refrigerants that may affect the purity of used FCs. Meanwhile, from economic aspect observation, there is lack in financial support available for installing destruction facilities. Only one destruction facility exists in each country, but the countries may need more to reduce overall costs (destruction cost + transportation cost). The Montreal Protocol's fund covers costs for purchasing recovery machines and reclamation equipment, but not covering the installation cost for a destruction facility. Issues on cost arise when there is no clear mechanism on payer responsibility for collection and transportation costs due to lack of regulations. High transportation cost of used FCs as many countries classify them as hazardous wastes (except for Malaysia). Less competitive on virgin FCs cost that are too cheap make it difficult to have consensus framework to cover handling cost of used FCs in near future if no incentive on reclaimed FCs being imposed.

3.2 Usage of refrigerant type and emission comparison by zone

Referring to Table 5, it shows the 6,651 total of split unit air conditioning system inside Universiti Teknologi Malaysia (UTM). There is about 4,261 units (64.1%) are using R-22 (HCFC) and 2,390 (35.9%) are using R-410A (HFC). The number of percentages still using R-22 (HCFC) are big. As could be observed, Zone 1 contained the highest number of R-22 (HCFC) and R-410A (HFC) which total in 2,399 split unit system. Zone 2 703 unit (55.4%) using R-22 (HCFC) 566 unit (44.6%) using R-410A (HFC). Zone 3 1,380 unit (71.9%) using R-22 (HCFC) 538 unit (28.1%) using R-410A (HFC). The lease total amounts of split unit air-conditioning system are located at Zone 4 with the total of 1,065 comprising of 766 units (71.9%) and 299 units (28.1%) using R-22 (HCFC) and R-410A (HFC) respectively.

Table 5 Split unit air-conditioning by zone in Universiti Teknologi Malaysia

	R-22 (HCFC)	R-410A (HFC)	TOTAL
Zone 1	1,412	987	2,399
Zone 2	703	566	1,269
Zone 3	1,380	538	1,918
Zone 4	766	299	1,065
TOTAL	4,261	2,390	6,651

The different between Zone 1 and Zone 4 are the usage and number of offices in that area. Zone 1 is denser in terms of air conditioning system and Zone 4 is located in a more recent development phase. Table 5 shows the calculated direct and indirect carbon emission from both R-22 (HCFC) and R-410A (HFC) for all four zones. Due to the high usage of refrigerant at Zone 1, hence it contributes to a higher amount of indirect and direct carbon release. As for R-410A (HFC), it is known that this refrigerant contribute to a much higher direct carbon release.

Table 6 Comparison of the for two type of refrigerants

	Zone 1		Zone 2	
	R-22	R-410A	R-22	R-410A
Direct emission (t eq CO_2/year)	1,789.0	38,987.5	893.7	22,357.6
Indirect emission (t eq CO_2/year)	55,484.0	33,796.7	27,550.1	19,601.9
	Zone 3		Zone 4	
	R-22	R-410A	R-22	R-410A
Direct emission (t eq CO_2/year)	1,748.5	21,251.5	1,552.8	11,228.5
Indirect emission (t eq CO_2/year)	54,128.5	15,291.4	29,297.5	15,514.3

3.2.1 Direct emission

Table 6 also shows that Zone 1 has a high direct emission compared to Zone 2, Zone 3 and Zone 4. This is also closely related to the number of air-conditioning units available in each zone. Table 6 shows that Zone 1 has a high number of air-conditioning units. For units using refrigerant R-22 (HCFC) are 1,412 units while those using R-410A (HFC) are 987 units. Although the number using refrigerant R-22 (HCFC) is higher, the direct emission amount is lower than the unit that used the R-410A (HFC) unit which is 1,789.0 t eq CO_2/year. As seen in Zone 1 has 987 units of air-conditioning and the amount of direct emission is 38,987.5 t eq CO_2/year. Zone 2 has 566 units of air-conditioning, Zone 3 has 538 units while Zone 4 has 299 units and it shows direct emissions 22,357.6 t eq CO_2/year, 21,251.5 t eq CO_2/year and 11,228.5 t eq CO_2/year respectively. In Zone 2, Zone 3 and Zone 4 can also be seen value direct emission for R-22 (HCFC) lower than R-410A (HFC). This is cause by the GWP for R-410A (HFC) is higher compared to R-22 (HCFC) which is 2,090 and 1,810 respectively. R-410A (HFC) does not contain the ozone depleting potential. In addition, it was calculated that the total direct emissions for R-22 (HCFC) was 5,984 t eq CO_2/year and for R-410A (HFC) was 93,825.1 t eq CO_2/year. Then, the total overall in the UTM was 99,809.1 t eq CO_2/year. This means that the air-conditioning systems that contribute direct high emission is R-410A (HFC) which is about 94% and R-22 (HCFC) only contribute 6%.

3.2.2 Indirect emission

In Table 6 shows that Zone 1 has a high indirect emission compared to Zone 2, Zone 3 and Zone 4 as Zone 1 has a high number of air-conditioning units. In UTM the total amount of indirect emission is 250,664.4 t eq CO_2/year with 6,651 units of air-conditioning. For refrigerant using R-22 (HCFC) are 4,261 units while R-410A (HFC) are 2,390 units which contribute 166,460.1 t eq CO_2/year, 84,204.3 t eq CO_2/year respectively. For indirect emission is related to emission of greenhouse gases associated with the electricity usage (Islam et al., 2017). Therefore, the TEWI will be greatly influenced by the performance of the cooling system energy consumption data, influenced by the efficiency of the system. Hence, the less energy required to produce each cooling kW, less will affect global warming.

3.2.3 Total Equivalent Warming Impact (TEWI)

TEWI provides a measure of the environmental impact of greenhouse gases from operation, services and final disposal of equipment (R. Sand et al., 1997). Direct emission and indirect emission have been combined to obtain the TEWI illustrated in Figure 4.

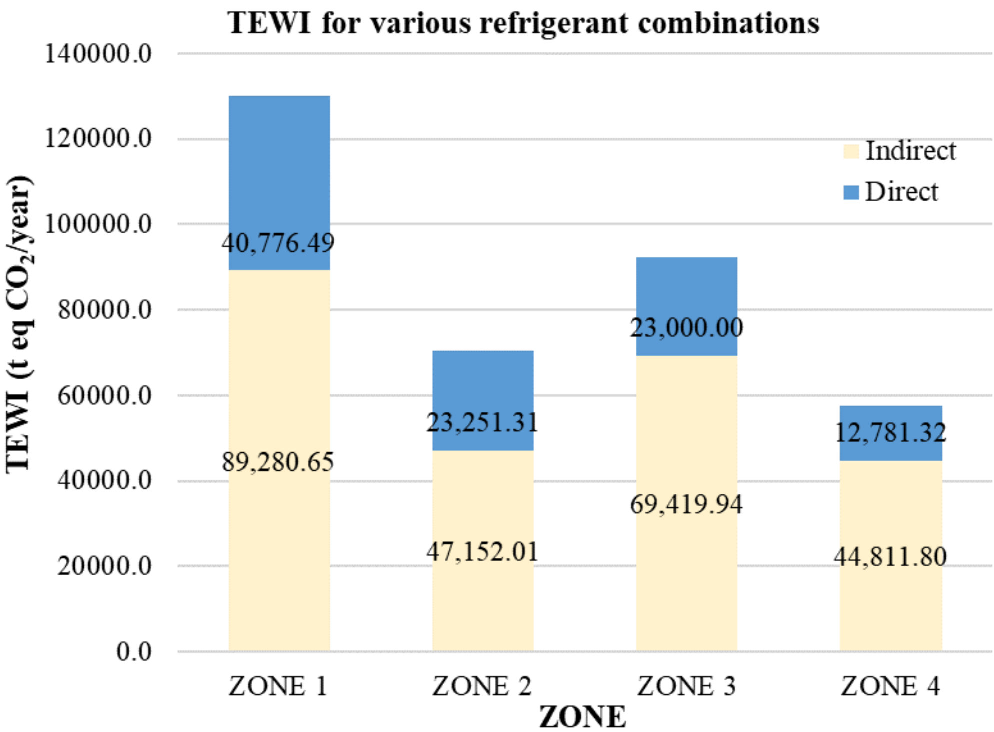

Figure 4: TEWI for various zone inside UTM

Evidently, Figure 4 shows the Total Equivalent Warming Impact (TEWI) in respective zoning area combining both direct and indirect release of R-22 (HCFC) and R-410A (HFC). For all four zoning area, indirect carbon emission contributes the most in carbon emission compared to direct carbon emission. In the graph in Figure 4, the total number of TEWI shows the largest value is in Zone 1 of 130,057.14 t eq CO_2/year followed by Zone 3, Zone 2 and Zone 4 of 92,419.94 t eq CO_2/year, 70,403.32 t eq CO_2/year and 57,593.12 t eq CO_2/year respectively. Hence, the total direct and indirect emission in UTM is 350,473.52 t eq CO_2/year.

3.2.4 Leakage rate

As could be observe in Table 7, the air-conditioning unit that uses R-22 (HCFC), the percentage of refrigerant leaks is over 100% in all zones inside UTM. Zone has the highest percentage of refrigerant leakage is in Zone 4, which is 473.79% for the use of R-22 (HCFC), while 87.43% are using R-410A (HFC). Even tough Zone 4 is at a more recent project compared to other zone, refrigerant could also leak during installation and maintenance. As for Zone 1, Zone 2 and Zone 3, the leakage rate is at 9.36%, 3.69% and 7.96% respectively which using R-410A (HFC) is lower comparative to its R-22 (HCFC) leakage rate for the same zoning area. For R-22 (HCFC) most of the zones having a high percentage of leakage is because most of the units that use the R-22 (HCFC) are old units and most of them are almost 10 years old. When the unit is used too long, the efficiency of the system for an air-conditioning unit has decreased. Refrigerant leakage happened are usually due to installation fault, poor services procedures, and inadequate maintenance. Even it become worst if there is existing problems by keep adding refrigerant to a unit system that is already full. If there is a leaks, the solution is not simply adding the refrigerant. The qualified technician should fix any leaking that happened in that units, test the repair, and lastly adding refrigerant into the unit system with the correct amount of refrigerant.

Table 7 Leakage Rate

	Leakage Rate (%)	
	R-22 (HCFC)	R-410A (HFC)
Zone 1	365.78	9.36
Zone 2	428.84	3.69
Zone 3	325.67	7.96
Zone 4	473.79	87.43

3.3 Recovery potential rate during on site disposal

This study also looks at the potential of how to treat refrigerant from dismantle chiller unit. For this objective, the sample only on HCFC which is R-123. In order to be part of the study, R-123 (HCFC) are collected from a chiller unit in Block C12, UTM which focus on recoverable phased-out refrigerant. Data on the refrigerant is collected from the sample to determine the recoverable potential of the collected refrigerant. The Figure 5 below is the following improvement suggested for refrigerant management in the context for UTM to trace FCs collection.

3.3.1 Sample extraction

The refrigerant that needed to be extracted from the system was found to be 311.5 kg in 4 drums. The sample received from Block C12 was focused in determining the impurities that were present. The possibility of impurities may be due to the contamination of foreign substances or because of the accidental exposure. The contaminant present in the refrigerant would reduce the cooling performance as it distorts the density and volume. If impurities are existing, it will be extracted and filtered. The process would normally take up to two weeks.

This helps in better handling and extraction, also prevents most of the unintended FCs to be released into the atmosphere.

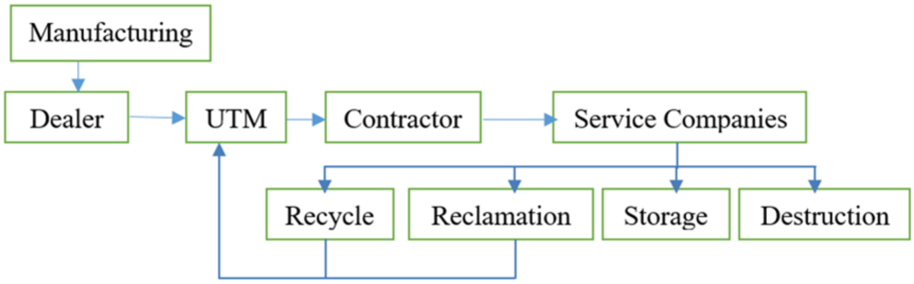

Figure 5: Refrigerant Handling Flow in UTM

3.3.2 Reclamation Process

The used refrigerants should be tested as to verify that it has attained AHRI 700 or ISO 12810, or equivalent specification prior to resale as required by the U.S. Environmental Protection Agency (EPA) (Damodaran and Donahue, 2010). The specification is compulsory under AHRI 700 standards and it must be taken into account to determine if the sample could be reclaimable. Non-reclaimable refrigerants must be disposed in an environmentally acceptable manner, and in accordance with the applicable regulations (Baxter et al., 2016). Chiller in Block C12 is one of targeted unit for phase-out HCFC to HFC. In order, to install new unit of HFC, the existing unit that use HCFC will be disposed. As for the Block C12 building, chiller system was converted to R-134A (HFC). R-134A (HFC) was selected to replace R-123 (HCFC) because HCFCs have been designed to phase-out by the Montreal Protocol and this means that R-123 (HCFC) will phase-out for HVAC she is just starting 1 January 2020. In the same time, R-123 (HCFC) have little ODP and to R-134A (HFC) have no ODP. In the present, R-134A (HFC) is the best choice for use in positive pressure equipment.

Table 8: The results of impurity testing

Drum	Weight (kg)	Impurity, % by Weight	Impurity Test	Result
1	96.5	0.47	<0.5%	Pass
2	74.5	0.49	<0.5%	Pass
3	90.5	0.49	<0.5%	Pass
4	50.0	0.48	<0.5%	Pass

The contamination present in all of the samples is shown in Table 8 which indicates that the sample is not contaminated by other factors and only shows the presence of trace amount of impurities during the testing of the sample. It was found that all of the sample passed the AHRI-700 specification standard, which is a good indicator for the sample to be reclaimable. The sample can be reuse into the chiller system and will reduce the need of introducing a new batch of R-123 (HCFC) into the system. If there is no need of new batch for R-123 (HCFC) in the existing installed system, it will help in reducing the R-123 (HCFC) manufacturing and reduces carbon emission because R-123 (HCFC) also consist of a carbon compound. The chiller air conditioning system can accept the reclaimed refrigerant only after it is being approved under the AHRI Standard. The refrigerant that undergoes reclaim process must be used in the same system. As shown in Table 8, the sample collected from Block C12, passed all of the impurity testing, it can undergo the process of reclamation.

3.3.3 Recovery rate

As shown in Table 9, initially transported weight was found to be 311.5 kg, whereas the process weight got reduced to 202.0 kg, minus the drum weight and extraction of impurities. The final weight after recoverable process was 160.0 kg and now it is considered to be ready for reuse in the chiller system. The total percentage loss after the process is found to be 20.79%. The loss of weight differing from one system to another system is due to the occurrence of contamination during the servicing and transportation of the sample. The other factors, which contributed to contamination is during the maintenance, whereby the system would be infiltrated due to improper services and accidental exposure.

Table 9: Reclaimed amount and percentage loss

No	Reclaimed Amount	Amount
1	Transported weight (kg)	311.5
2	Processed weight (kg)	202.0
3	Final net weight (kg)	160.0
	Total percentages loss (%)	20.79
	Recoverable R-123 (HCFC) (%)	79.21

In order to determine, whether the processed refrigerant meets or exceeds the product specifications, the processed refrigerant was required to be compared the new refrigerant after the process of reclamation. There is an estimated loss of recoverable gases whereby it is estimated only 70% of the recovered gas can be regenerated by filtering and distillation. This is due to the 30% degradation of fluid characteristic that is not allowable for reuse. It is also hypothesized that 1% of the fluid is emitted in the atmosphere because of the reclamation procedure, 1 % is composed of impurities (Cascini et al., 2016). As in this study, the amount of R-123 (HCFC) recoverable refrigerant is 79.21%.

4. Conclusions

Managing fluorocarbon refrigerant gases initiatives would support Sustainable Development Goals (SDGs) Goal 1End Poverty, Goal 2 End Hunger, Goal 3 Health and Well Being, Goal 7 Affordable Energy, Goal 9 Innovation and Infrastructure, Goal 12 Responsible Consumption and Production and Goal 13 Climate Action (UNDP,2014). Sound management of fluorocarbons from life cycle perspective is important and have high urgency to its implementation. Direct benefits from fluorocarbons management brings multiple effects for environmental conservation which is recovery of ozone layers, climate benefits, promotion of energy efficiency and realization of proper disposal of e-waste; while maximization of these initiatives are expected to lead to co- benefit in protecting health, driven industry innovation, creating job opportunities as well as more-efficient energy usage. Therefore, having immediate and long term fluorocarbon refrigerant management plan that considering involvement of stakeholders at policy level, controlling leakage at consumption level, and environmentally sound waste management options at post consumption level is crucial. Hence, it is important to implement effective awareness raisings through collaborations with existing measures such as climate change, energy efficiency and e-waste management to get end-users attentions on co-benefits value of it.

Acknowledgements

This work was carried out with collaboration from project partner in selected ASEAN countries under coordination by Mitsubishi UFJ Morgan Stanley and E&E Solutions Inc, supported by The Ministry of the Environment, Japan (MOEJ) under project 'Feasibility study on promotion of energy saving equipment and environmentally sound management of used fluorocarbons in Indonesia, Thailand, Malaysia and Vietnam" (registered under UTM contract research grant 4B242 and 4C205). The authors would like to acknowledge the efforts and contribution of Universiti Teknologi Malaysia Office of Asset and Development (UTM OAD), Office of Vice Chancellor and Office of Deputy Vice Chancellor (Development).

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