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Original article

Title: Implication of the Cluster Analysis Using Greenhous Gas Emissions of Asian Countries to Climate Change Mitigation

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ABSTRACT

Climate change caused by excessive emission of greenhouse gases (GHGs) into the atmosphere has gained serious attention from the global community for a long time. More and more countries have decided to propose their goals such as Paris agreements, to reduce emitting these heat trapping compounds for sustainability. The Asian region houses dramatic changes with diverse religions and cultures, large populations as well as a rapidly changing socio-economic situations all of which are contributing to generating a mammoth amount of GHGs, hence they require calls for related studies on climate change strategies. After pre-filtering of GHG emission information, twenty four Asian countries have been selected as primary target countries. Hierarchical cluster analysis method using complete linkage technique was successfully applied for appropriate grouping. Six groups were categorized through GHG emission properties with major and minor emission sectors based on the GHG inventory coverings energy, industrial processes, agriculture, waste, land use change and forestry and bunker fuels. Assigning six groups using cluster analysis finally implied that the approach to establish GHG emission boundaries were meaningful to develop further mitigation strategies. Following the outcome of this study, calculating amount of reduction potential in suitable sectors as well as determining best practice, technology and regulatory framework can be improved by policy makers, environmental scientists and planners at the different levels. Therefore, this work on reviewing a wide range of GHG emission history and establishing boundaries of emission characteristics would provide further direction of effective climate change mitigation for sustainability and resilience in Asia.

Keywords: GHGs inventory; cluster analysis; Asian countries; climate change mitigation

1. INTRODUCTION

Global warming and climate change produced by superfluous emission of greenhouse gases (GHGs) into the atmospheric environment is an insistent concern for both the mother nature and human-beings. Due to the potential impacts of extreme weather, for instance, abnormal climate changes, rising sea levels, cyclones, droughts and the issues of desertification as well as loss of biodiversity, the United Nation Framework Convention on Climate Change (UNFCCC) 21st Conference of the Parties recently made the Paris agreement (COP21) to reflect even further intensified restriction (Rhodes 2016). In fact, global climate change and its unspecified impacts have lasted for ages long across the world. In Bangladesh, more than 130,000 people were killed in April 1990 due to unprecedentedly fierce storm (Huq 2001), the Himalayas, reserving the largest glaciers except the polar region, have lately been melting down due to increasing global temperature (Bajracharya et al. 2007), and even the global warming in South Asia is mostly to be above the global average (Knox et al. 2012). Moreover, Clarke et al. (2007) has reported that the concentration of carbon dioxide in the atmosphere will be elevating up to between 700ppmv and 900ppmv in 2100, considering the growth in world populations to 9.9 billion, GDP growth patterns with historical experience and background, energy production as well as consumption based on the three different models, namely IGSM, MERGY and MiniCAM.

Although the formal negotiation of Kyoto Protocol in 1997 with instruments that Emission Trading (ET), Clean Development Mechanism (CDM) and Joint Implementation (JI) had been developed and implemented, it was not sufficiently affordable to reach successful international climate cooperation for reduction of GHG emissions (Falkner 2016). As result of Paris agreement, 195 countries including not only Annex I and Annex II but also Non-Annex I countries have agreed and proposed their greenhouse gas reduction goals through implementing Intended Nationally Determined Contribution (INDC) for sustainability and resilience in global village (UNFCCC 2015). The Asian region maintains dynamic changes owing to its large amount of inhabitants coming from variety of religious, cultural and economic backgrounds which can provide an interesting and important case for a sensational study in terms of the impact on the environment (Marcotullio et al. 2012). Furthermore, Botzen et al. (2008) reported that average annual growth, especially in energy-related carbon dioxide emissions between 2004 and 2030 of major countries in Asia such as China (3.4%) and India

(2.6%) overtake USA (1.1%), even more than the total growth of the world (1.8%). Thus, this paper has aimed to explore the GHG emission characteristics among the 24 Asian countries (Armenia, Azerbaijan, Bangladesh, Brunei, Cambodia, China, Cyprus, India, Indonesia, Iran, Iraq, Japan, Kazakhstan, South Korea, Kuwait, Mongolia, Myanmar, Nepal, Oman, Pakistan, Thailand, Turkey, United Arab Emirate and Vietnam) using $R^{®}$; a language for statistical analysis and visualization.

There are more and more research articles with different perspectives on the analysis of climate change mitigation implementations at the assorted levels (Backman et al. 2017; Kafle et al. 2017; Mottet et al. 2017; Wigand et al. 2017). Even if numerous scientists and decision makers have suggested climate strategies covering public policy, national GHG reduction plan as well as regional climate response, not much incisive intimations were introduced. For those reasons, cluster analysis was applied on the basis of GHG emissions inventory data highlights in 2013 and 6 sectoral emission data; Energy, Industrial process, Agriculture, Waste, Land-Use Change and Forestry (LUCF) as well as Bunker fuel from 2004 to 2013 in order to clarify the emission patterns and their properties. At the same time, the result of this article that drawing boundaries according to GHG emission peculiarities finally shepherds to develop further climate change mitigation strategies. Therefore, this paper analyzing GHG emission history across certain Asian countries by using cluster technique and by investigating the possibly reducible sectors will be providing keen insights to drive further climate mitigation strategies for well-being of humanity and ecology.

2. METHODOLOGY

2.1 Literature review

Geographically, The Asian region is mainly subdivided into five areas that Eastern Asia, Southeast Asia (Indochina peninsula and the Malay Archipelagos), Southwest Asia, Central Asia and Southern Asia with 47 independent countries as in Table 1.

Table 1. Geographically and historically classified independent countries in Asian region

Eastern Asia		China	Japan	Korea, Dem. Rep.
		Korea (South)		
Southeast Asia	**Indochina peninsula**	Cambodia	Laos	Myanmar
		Thailand	Vietnam	
	Malay Archipelagos	Brunei	East Timor	Indonesia
		Malaysia	Philippines	Singapore
Southwest Asia		Afghanistan	Armenia	Azerbaijan
		Bahrain	Cyprus	Georgia
		Iran	Iraq	Israel
		Jordan	Kuwait	Lebanon
		Oman	Qatar	Saudi Arabia
		Syria	Turkey	United Arab Emirates
		Yemen		
Central Asia		Kazakhstan	Kyrgyzstan	Mongolia
		Tajikistan	Turkmenistan	Uzbekistan
Southern Asia		Bangladesh	Bhutan	India
		Maldives	Nepal	Pakistan
		Sri Lanka		

The Climate Access Indicators Tool (CAIT, http://cait.wri.org), the main data source in this paper is an online visualization explorer organized by World Resources Institute (WRI). CAIT contains amazingly useful GHG emissions data in worldwide that can provide UNFCCC climate negotiations by sharing a novel approach to climate equity. The raw data is basically available for the period 1990 to 2013 and the data source of each country is compiled by globally prestigious agencies and organizations; International Energy Agency (IEA), international energy statistics; U.S Energy Information Administration (EIA), global non-CO_2 GHG emissions; U.S Environmental Protection Agency (EPA) as well as agriculture statistics;

Food and Agriculture Organization of the United Nations (FAO).

Many utilized data is also accessible such as CO_2 and/or GHG emission data per capita, socio-economic (e.g. population, GDP-USD and energy use) per capita, CO_2 and/or GHG emission data per GDP as well as cumulative population and energy use per GDP from 1960's. Unfortunately, there are some missing data or inaccurate emission history to refer through. For example, Afghanistan does not have emission data, especially in energy sector and land-use change and forestry (LUCF). Georgia, Israel, Jordan, Qatar, Saudi Arabia, Tajikistan, Turkmenistan and Yemen have no LUCF data for several years, and there is no energy sector data in Bhutan during recent 10 years of 2004 to 2013. Laos and Maldives have omitted data from energy and bunker fuels for the target years. In case of Syria, none of data has been updated during the target period. Furthermore, Afghanistan, Bhutan, Laos, Maldives and some other countries have omitted energy subsector that electricity and heat, manufacturing and construction, transportation, other fuel combustion as well as fugitive emission. All acceptable cases including data repletion, geographical and economical diversity as well as the population considered, it has been filtered and determined that 24 countries (see Table 2) are eligible for available recent 10 years (2004-2013) of GHGs emissions from the CAIT data resource.

As several previous papers have already studied that economic status and GHG emission are closely related due to energy consumption and urbanization (Aaheim et al. 2012; Li et al. 2016; Marcotullio et al. 2012; Timilsina and Shrestha 2009). Furthermore, Dulal and Akbar (2013) emphasized that the main four factors consisting of economic base of the cities, urban formation, transportation structure and lay out as well as waste management system contribute to the growing emissions from the cities. Therefore, it is required to understand different kinds of social trends including population, GDP and economical background as shown in Table 2.

Table 2. Selected countries in Asia for GHG emission analysis

Country	Population [1]	Nominal GDP [2] (Billions USD)	Economical history [3]	Country	Population [1]	Nominal GDP [2] (Billions USD)	Economical history [3]
Armenia	3,051,250	10.74		Kazakhstan	18,360,353	157.88	
Azerbaijan	9,872,765	38.62		Korea (South)	51,732,586	1,498.17	
Bangladesh	156,186,882	248.85		Kuwait	2,832,776	110.52	
Brunei	436,602	12.33		Mongolia	3,031,330	10.27	
Cambodia	15,957,223	20.95		Myanmar	56,890,418	72.37	
China	1,373,541,278	11,391.67		Nepal	29,033,914	23.32	
Cyprus	1,250,575	19.64		Oman	3,355,262	71.33	
India	1,266,883,598	2,451.24		Pakistan	201,995,540	270.95	
Indonesia	258,316,051	1,020.07		Thailand	68,200,824	432.91	
Iran	82,801,633	368.43		Turkey	80,274,604	793.72	
Iraq	38,146,025	189.43		United Arab Emirates	5,927,482	407.21	
Japan	126,702,133	4,730.32		Vietnam	95,261,021	215.83	

1) Central Intelligence Agency, CIA (2016)

2) International Monetary Fund, IMF (2016)

3) World Bank (2004-2015)

2.2 Cluster analysis

The principal of pattern recognition is introduced into various parts of the study such as mechanical engineering, medical science, computer vision, marketing, biology and psychology (Al-Nuaimy et al. 2000; Jain et al. 2000; Wright et al. 2010). Pattern recognition is known as grouping method according to specific criteria and it is typically classified into variety of problems like description, classification and clustering. In this paper, optimal cluster methodology was applied in order to assign suitable groups that represent particular emission characteristics, and thus this will provide further direction to develop climate change mitigation. There are two standard clustering strategies including hierarchical clustering and partitioning (non-hierarchical) methods (e.g. K-means algorithm, PAM; partitioning around medoids and CLARA; clustering large applications) (Ferrari and De Castro 2015; Kaufman and Rousseeuw 2009; Zadegan et al. 2013) as described in Figure 1.

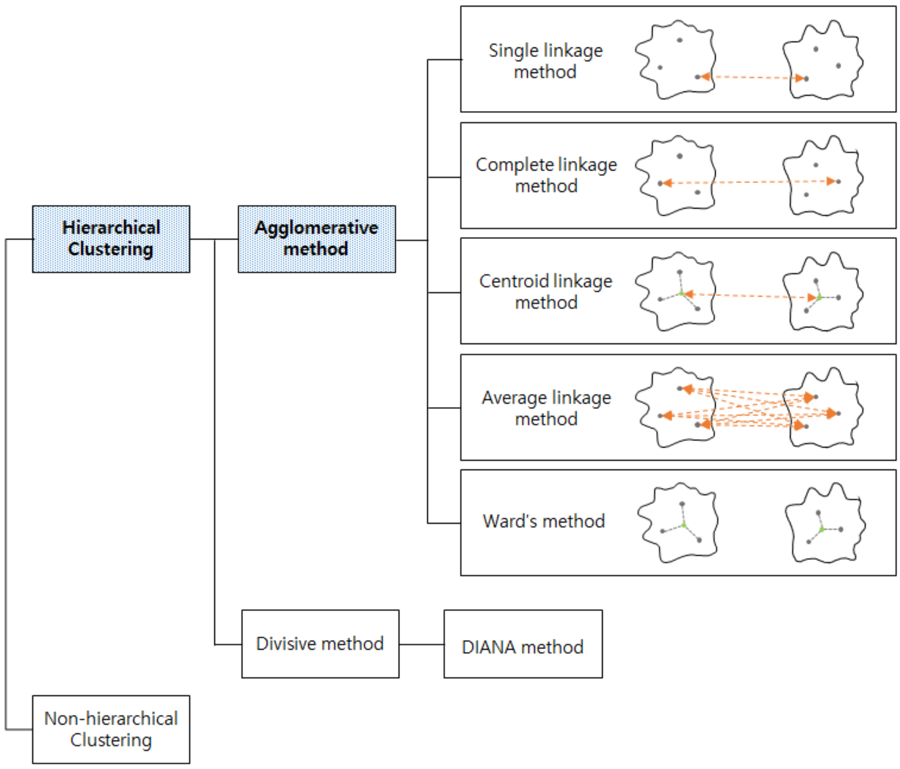


Figure 1. Conceptual diagram for hierarchical clustering

We adopted hierarchical technique since it is not required to pre-specify the number of clustered group whereas K-means clustering requires so (Li et al. 2014). Hierarchical clustering is commonly designed by two types of methods which are the agglomerative hierarchical method and divisive hierarchical method (Bouguettaya et al. 2015). The agglomerative method known as AGNES starts with n (the number of observations) groups and gradually merges into the most similar groups until one station is left. The divisive clustering (DIANA), on the other hand, is the opposite of agglomerative method that begins with one large cluster and consecutively split the root until the all objects have a small single leaf. However, agglomerative clustering is preferred rather than DIANA because of its computational efficiency (Webb 2003). In addition, there are commonly five different methods onto agglomerative hierarchical clustering, in particular single linkage, complete linkage, centroid linkage, average linkage and Ward's method according to the calculation methods of distance between each cluster (Bouguettaya et al. 2015; Murtagh and Legendre 2014). Single linkage method computes the smallest distance between clusters and merge using minimum distance (Ferrari and De Castro 2015). Complete linkage, on the contrary, defines the maximum distance calculated between the observations (Ryberg 2015). Centroid linkage considers the distance calculated between the centroids of two groups (Kasneci et al. 2014). Whenever an observation is added or subtracted, the centroid distance is recalculated. The distance between two different groups using average linkage method that starts similar way as single and complete linkage considers the cluster criterion as average distance (Sibley et al. 2014). Ward's method uses the incremental sum of the squares between two similar group and it minimizes the total within cluster variance (Martinez and Martinez 2007). Hence, each clustering linkage can be computed by distance matrix following in Figure 2.

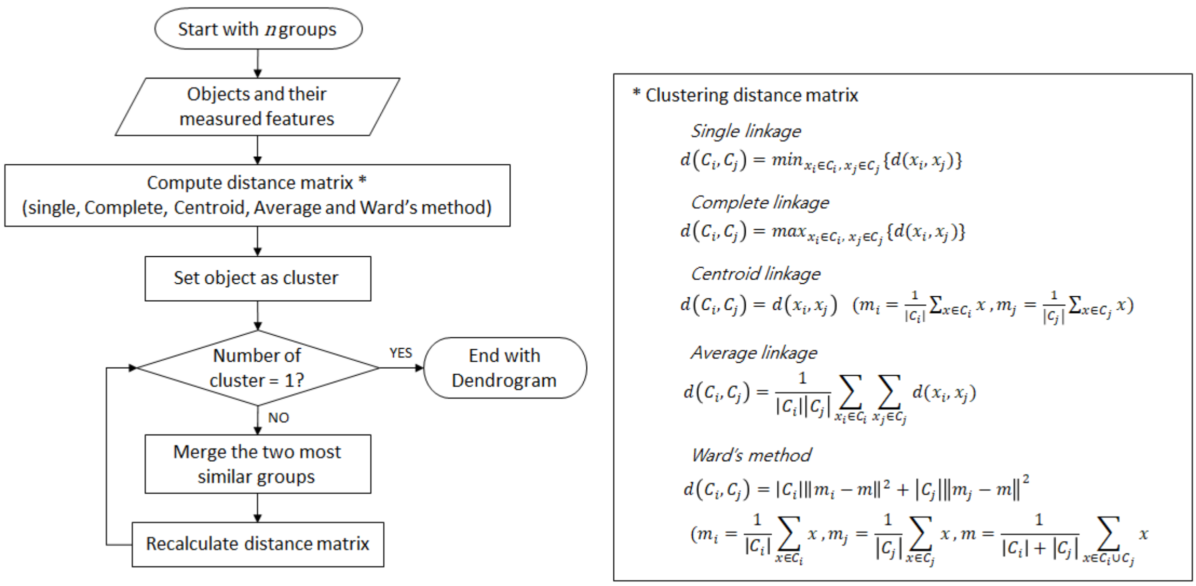


Figure 2. Agglomerative hierarchical clustering algorithm

3. RESULT AND DISCUSSION

3.1 Overview of GHG emissions

This study has reviewed the GHG emission properties in 24 Asian countries including Armenia, Azerbaijan, Bangladesh, Brunei, Cambodia, China, Cyprus, India, Indonesia, Iran, Iraq, Japan, Kazakhstan, South Korea, Kuwait, Mongolia, Myanmar, Nepal, Oman, Pakistan, Thailand, Turkey, United Arab Emirate and Vietnam. All selected countries in this study with the exception of Cambodia and Cyprus, experienced momentous GHGs emission growth during the years of 2004 to 2013. As seen from Table 3, China (45.88%), India (43.31%) and Iraq (41.72%) have the most dramatic growth rate whereas the world has 14.22 % of growth rate. Particularly, the GHG emission growth rates of most selected countries that China, India, Iran, South Korea, Thailand, Pakistan, Turkey, Kazakhstan, Iraq, United Arab Emirates, Vietnam, Kuwait, Bangladesh, Oman, Mongolia, Azerbaijan, Nepal and Armenia are higher than the world average which indicates rapid growth of GHG emissions. On the contrary, two countries, Cambodia and Cyprus have remarkably decreased which rarely happens compared to the international trend, even though the declined amount is not that high.

Table 3. Comparison of GHG emissions growth between the year of 2004 and 2013 including Land-Use Change and Forestry (LUCF)

Rank	Country	2004 (Mt CO_2eq)	Country	2013 (Mt CO_2eq)	Rate (%)
	World	42,341.58	World	49,362.63	14.22
	Asia	16,088.41	Asia	24,251.33	33.66
1	China	6,250.72	China	11,467.59	45.88
2	Indonesia	1,877.73	India	3,047.67	43.31
3	India	1,727.85	Indonesia	2,163.73	13.22
4	Japan	1,298.90	Japan	1,393.35	6.78
5	Korea (South)	543.19	Iran	797.20	32.61
6	Iran	537.24	Korea (South)	673.62	19.36
7	Thailand	317.85	Thailand	398.50	20.24
8	Turkey	281.06	Pakistan	356.30	22.23
9	Pakistan	277.09	Turkey	350.49	19.81

10	Kazakhstan	200.10	Kazakhstan	314.31	36.33
11	United Arab Emirates	184.79	Iraq	284.35	41.72
12	Myanmar	175.77	United Arab Emirates	281.53	34.36
13	Kuwait	165.82	Vietnam	241.82	34.06
14	Iraq	165.72	Myanmar	201.58	12.80
15	Vietnam	159.47	Kuwait	201.26	17.61
16	Bangladesh	149.77	Bangladesh	194.01	22.80
17	Oman	66.42	Oman	106.02	37.35
18	Cambodia	52.84	Mongolia	63.61	25.13
19	Azerbaijan	52.64	Azerbaijan	62.68	19.07
20	Mongolia	47.62	Cambodia	51.86	-1.90
21	Nepal	34.05	Nepal	42.63	20.11
22	Brunei	18.82	Brunei	19.92	5.48
23	Cyprus	9.56	Armenia	8.59	25.79
24	Armenia	6.38	Cyprus	8.16	-17.16

In addition, the total GHG emissions (Mton CO_2eq) and its sectoral emission data including the each percentage in 2013 are summarized in Table 4. Each selected country has different emission characteristics possibly influenced by their population, economic situations (GDP growths), industrial structures (*e.g.* primary industry, secondary industry and tertiary industry), waste management system, energy generations and usage (*e.g.* thermal power generation, nuclear power generation, the amount of fossil fuel use, renewable energy application), topographical features and land use (*e.g.* desert, mountainous area, alpine region and forest area) as well as climatic condition (*e.g.* tropical climate, temperate climate and dry climate) (An and Sauer 2004; Liu et al. 2012; Searchinger et al. 2008; Weisser 2007; Woodcock et al. 2009).

Table 4. Total GHG emissions including sectoral data and percentage in 2013

(Unit: Mt CO_2eq)

Country	Total GHG emissions	Energy (%)	Industrial process (%)	Agriculture (%)	Waste (%)	LUCF (%)	Bunker fuels (%)
World	49362.63	35520.28	3054.3	5179.42	1507.25	2996.05	1105.33
Armenia	8.59	5.94 (69.15)	0.60 (6.98)	1.35 (15.72)	0.71 (8.27)	-0.15 (-1.75)	0.14 (1.63)
Azerbaijan	62.68	59.59 (95.07)	1.49 (2.38)	6.42 (10.24)	2.23 (3.56)	-8.47 (-13.52)	1.42 (2.27)
Bangladesh	194.01	62.42 (32.17)	8.18 (4.22)	74.51 (38.41)	18.52 (9.55)	29.08 (14.99)	1.30 (0.66)
Brunei	19.92	18.48 (92.77)	0.26 (1.31)	0.14 (0.70)	0.15 (0.75)	0.38 (1.91)	0.51 (2.56)
Cambodia	51.85	7.30 (14.07)	0.63 (1.21)	18.78 (36.22)	0.39 (0.75)	24.57 (47.38)	0.19 (0.37)
China	11467.59	9430.23 (82.24)	1408.35 (12.28)	697.90 (6.08)	198.53 (1.73)	-312.08 (-2.72)	44.66 (0.39)
Cyprus	8.10	5.63 (69.46)	0.57 (7.04)	0.38 (4.69)	0.36 (4.43)	-0.30 (-3.76)	1.47 (18.14)
India	3047.67	2027.86 (66.54)	192.64 (6.32)	628.27 (20.62)	60.28 (1.97)	122.29 (4.01)	16.33 (0.54)
Indonesia	2163.73	489.11 (22.61)	30.23 (1.40)	160.28 (7.41)	64.72 (2.97)	1416.30 (65.47)	3.09 (0.14)
Iran	797.20	620.21 (77.80)	39.78 (4.99)	34.70 (4.35)	22.13 (2.78)	67.08 (8.41)	13.30 (1.67)
Iraq	284.36	260.98 (91.78)	6.10 (2.15)	8.62 (3.03)	8.88 (3.12)	-2.04 (-0.72)	1.82 (0.64)
Japan	1393.35	1240.08 (89.00)	87.48 (6.27)	21.23 (1.52)	4.55 (0.33)	7.47 (0.54)	32.54 (2.34)
Kazakhstan	314.31	286.10 (91.02)	4.50 (1.43)	18.41 (5.86)	4.72 (1.51)	0.08 (0.03)	0.50 (0.16)
Korea (South)	673.62	584.13 (86.72)	65.41 (9.71)	12.91 (1.92)	11.09 (1.64)	-39.60 (-5.88)	39.68 (5.89)
Kuwait	201.26	191.02 (94.92)	3.41 (1.69)	0.39 (0.19)	0.95 (0.47)	-0.02 (-0.01)	5.51 (2.74)
Mongolia	63.61	19.46 (30.59)	0.16 (0.25)	18.84 (29.62)	0.19 (0.30)	24.84 (39.05)	0.12 (0.19)
Myanmar	201.58	22.05 (10.94)	0.33 (0.16)	64.66 (32.08)	11.71 (5.81)	102.70 (50.95)	0.13 (0.06)
Nepal	42.63	11.86 (27.82)	1.54 (3.62)	21.84 (51.23)	0.81 (1.89)	6.27 (14.71)	0.31 (0.73)
Oman	106.02	96.37 (90.90)	2.89 (2.72)	1.60 (1.51)	0.93 (0.88)	0.00 (0.00)	4.23 (3.99)
Pakistan	356.30	156.30 (43.87)	16.75 (4.70)	147.06 (41.27)	6.67 (1.87)	28.60 (8.03)	0.92 (0.26)
Thailand	398.50	264.64 (66.41)	27.04 (6.79)	67.62 (16.97)	10.13 (2.54)	14.94 (3.74)	14.13 (3.55)
Turkey	350.49	291.65 (83.21)	38.12 (10.88)	43.81 (12.50)	34.88 (9.95)	-64.86 (-18.51)	6.89 (1.97)
United Arab Emirates	281.53	203.13 (72.15)	12.17 (4.32)	1.64 (0.58)	4.47 (1.59)	-0.21 (-0.07)	60.33 (21.43)
Vietnam	241.82	153.74 (63.58)	29.84 (12.34)	63.93 (26.43)	9.25 (3.83)	-17.67 (-7.31)	2.73 (1.13)

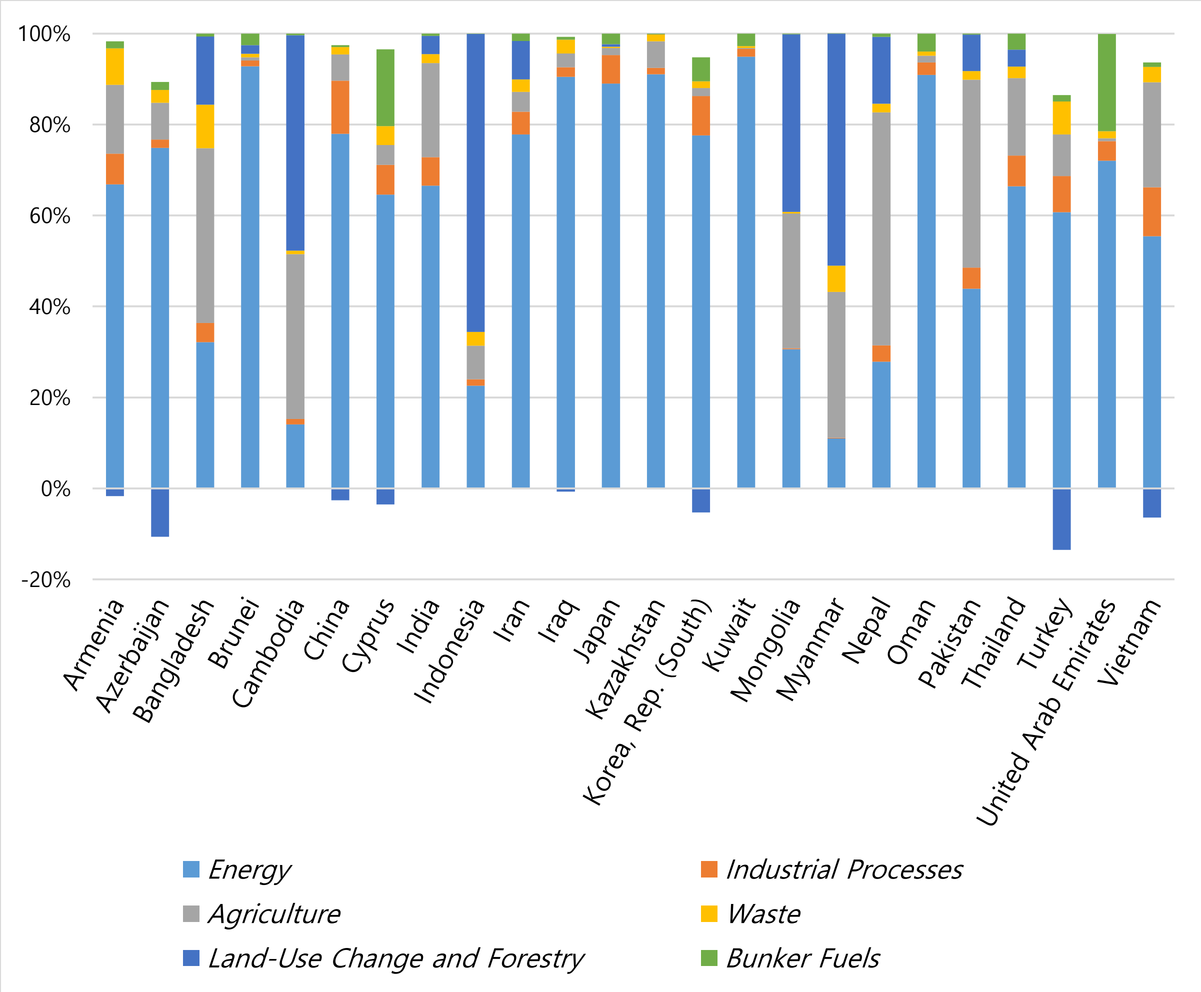


Figure 3. GHG inventory data (emission percentage) for selected countries in 2013

Most of countries in Figure 3, for example, have significant portion of emissions from energy sector, especially Azerbaijan, Brunei, Iraq, Kazakhstan, Kuwait and Oman are occupied by more than 90 % of energy sector. In addition, China, Japan, South Korea and Turkey also have more than 80 % of energy sector emissions. China, Turkey and Vietnam emit more than 10 % of total national greenhouse gases from industrial parts, besides India, Japan, South Korea and Thailand also generate comparably large amount of emission gas through industrial sector. Particularly, industrial processes are closely associated with major non-CO_2 greenhouse gases covering sulfur hexafluoride (SF_6, GWP: 22,800, when GWP of CO_2 is standardized as of '1') uses dielectric insulator, electronic equipment production including electric cables and buses as well as circuit switchgear (Sulbaek Andersen et al. 2017), nitrous oxide (N_2O, GWP: 298) which is the source of adipic acid and nitiric acid production (Zhang et al. 2015), and even applied for pain management during the medical treatment (Schneider et al. 2017), hydrofluorocarbons (HFCs, GWP: 124-14,800) normally used for semiconductor manufacturing and ozone depleting substances production (Zhang et al. 2015) as well as perfluorocarbons (PFCs, GWP: 7,390-12,200) generated in electrolysis process especially during anode effects (AEs) (Liu et al. 2016; Vogel et al. 2017). Although non-CO2 GHGs like SF_6, N_2O, HFCs and PFCs are generally of small amounts (Montzka et al. 2011), their usage is remarkably important in the dispute against global warming and climate change response due to high global warming potential (GWP, relative measure to compare global warming impacts) (Jiang et al. 2016). Some countries such as Bangladesh, Cambodia, India, Mongolia, Myanmar, Nepal, Pakistan and Vietnam have more than 20 % of total GHG emissions from agriculture sector. Interestingly, the emissions from agriculture sector in Bangladesh, Cambodia, Myanmar and Nepal are even higher than these in energy sector. In terms of land-use change and forestry (LUCF), it can be classified as two groups that positive quantities (+) of LUCF (Bangladesh, Brunei, Cambodia, India, Indonesia, Iran, Japan, Kazakhstan, Mongolia, Myanmar, Nepal, Pakistan, and Thailand) as well as negative quantities (-) of LUCF (Armenia, Azerbaijan, China, Cyprus, Iraq, South Korea, Kuwait, Turkey, United Arab Emirates and Vietnam). Those aspects can be determined as the contribution of forestry either carbon emission sources as a result of deforestation and degraded forest (+) or the sink of carbon through forest conservation and enhancing carbon storages in degraded forest land area (-) (Lasco and Pulhin 2000). Armenia and Turkey tend to emit comparably large amount of GHGs from waste sector mainly contributed by waste (or landfill), anaerobic digester biogas, incineration and wastewater. Referring bunker fuels used the most in vessel fuel, power generation, boiler fuel and factory machines, Cyprus (18.14%) and United Arab Emirates (21.43%) tend to emit relatively large amount of greenhouse gas.

3.2 Grouping methodology using effective clustering approach

In order to determine suitable clustering method, several hierarchical clustering techniques that single linkage, complete linkage, centroid linkage, average linkage and Ward's method were compared for reviewing GHG emission characters across Asian countries. One of the major issues when adapting cluster analysis is to define the best number of clusters for instance, which steps should be terminated on the clustering process. Figure 4 shows one of the approaches for hierarchical clustering to determine optimal clusters that elbow method; the distance between each cluster (correlation between selected countries) versus optimum number of clusters for complete linkage as guidance. According to the Figure 4, the value on y-axis (within groups sum of squares; value of differences between each station) rapidly goes down with increasing the number of clusters from 1. The elbow in the curve finally indicates number of clusters=6 that six is an affordable estimate of the number of clustering groups.

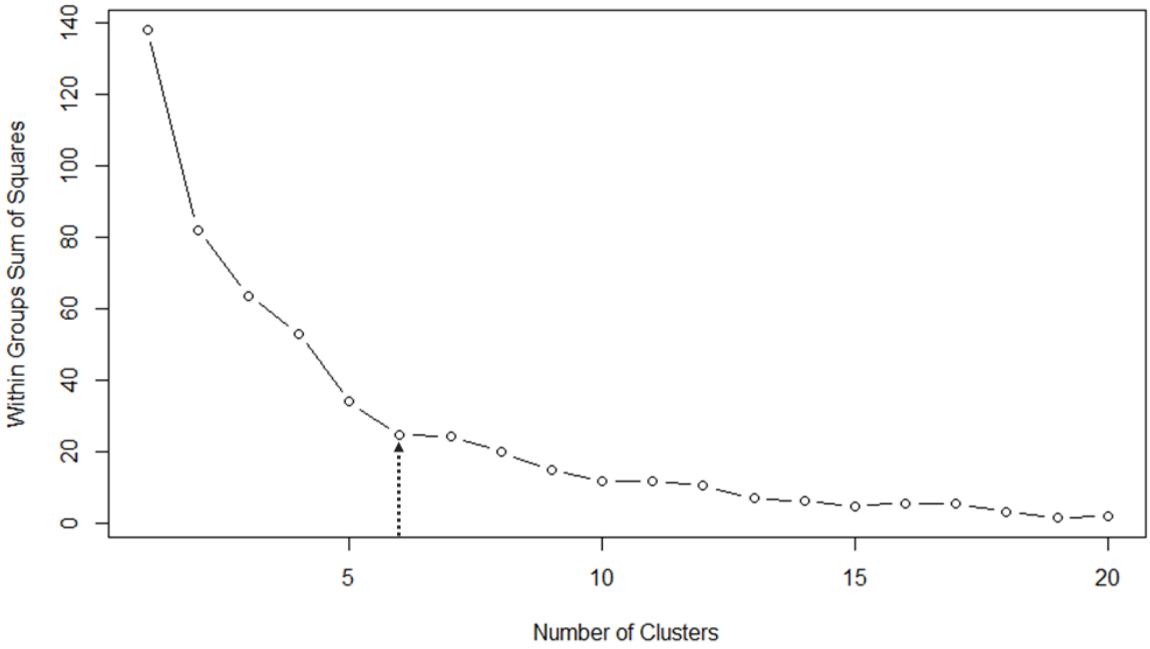


Figure 4. Determination for the suitable number of clusters

Table 5 summarizes the number of optimal clusters within different techniques of clustering method. It is certainly clear that single linkage technique arranges most of the groups (15 stations) into one cluster also, centroid and average linkage methods have 12 and 13 clusters in a single group. Ward’s methods has equally distributed the clusters than single linkage, centroid linkage and average linkage but not clearly arranged rather than complete technique. For example, Armenia, Turkey and Bangladesh gathered onto the same group, even though Bangladesh mainly emits the greenhouse gas through agriculture sector, whereas Armenia and Turkey mostly generate from energy and agriculture. Furthermore, emission tendency of LUCF are contrasting that Armenia and Turkey have the negative quantities while Bangladesh has the positive quantity which is not reasonably evaluated. Finally, Complete linkage method most reasonably assigns each station among the 24 clusters that Group A: 4; Group B: 3; Group C: 2; Group D: 3; Group E: 6; Group F: 6 as summarized in Table 5 and plotted in Figure 5.

Table 5. The number of clusters within each applied clustering method

Clustering method	A	B	C	D	E	F	G
Single linkage	2	1	2	1	15	1	2
Complete linkage	4	3	2	3	6	6	
Centroid linkage	2	1	1	5	12	1	2
Average linkage	2	4	2	13	1	2	
Ward's method	2	4	6	2	7	3	

Based on the technical knowledge and national GHGs inventory data in this paper, twenty four Asian countries have been analyzed with the most acceptable cluster model that complete linkage technique. Clustering solution using complete linkage has been performed as shown Figure 5 with cluster dendrogram. Six cluster groups were produced that Group A: Cambodia, Indonesia, Mongolia and Myanmar; Group B: Bangladesh, Nepal and Pakistan; Group C: Cyprus and United Arab Emirates; Group D: Armenia, Turkey and Vietnam; Group E: Azerbaijan, Brunei, Iraq, Kazakhstan, Kuwait and Oman; Group F: China, India, Iran, Japan, South Korea and Thailand.

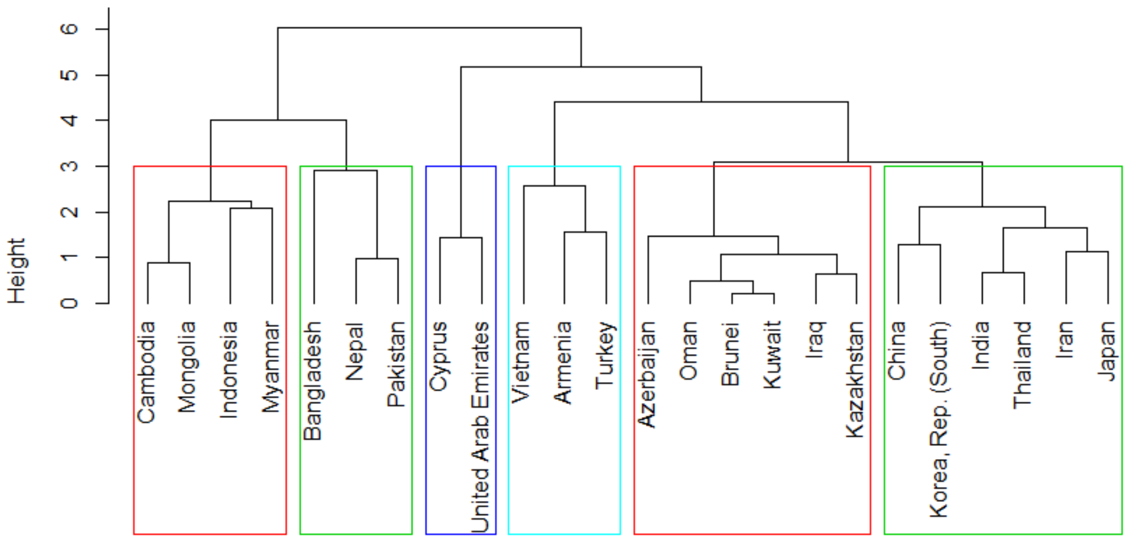


Figure 5. Cluster dendrogram computed by complete linkage technique

3.3 Sectoral analysis for the clustered groups

Based on the complete linkage solution, six groups have been assigned. Figure 6 to Figure 11 describe the greenhouse gas emissions histories for 10 years of 2004 to 2013. Group A; Cambodia, Indonesia, Mongolia and Myanmar particularly tend to emit from LUCF (Cambodia, 47.38%; Indonesia, 65.47%; Mongolia, 39.05% and Myanmar, 50.95%), agriculture (Cambodia, 36.21%; Indonesia, 7.41%; Mongolia, 29.62% and Myanmar, 32.08%) and following a little energy sector especially in Cambodia (14.08%), Indonesia (22.61%) as well as Myanmar (10.94%) in 2013 and these properties have been endured since 2004. On the other hand, all the countries in Group A generated extremely few amount of GHG through industrial process (0.72±0.49%) and bunker fuel (0.22±0.15%) during 10 years.

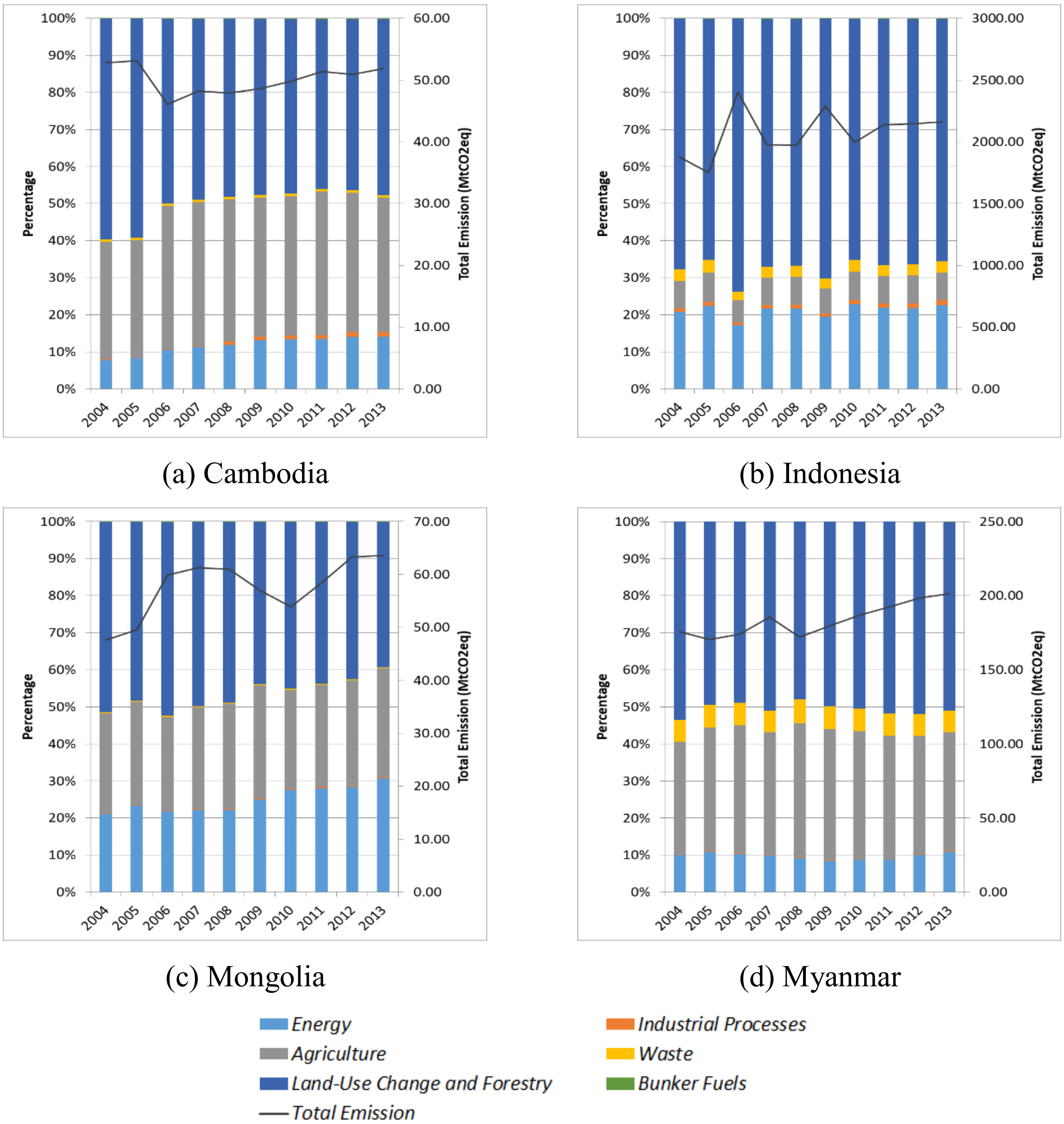
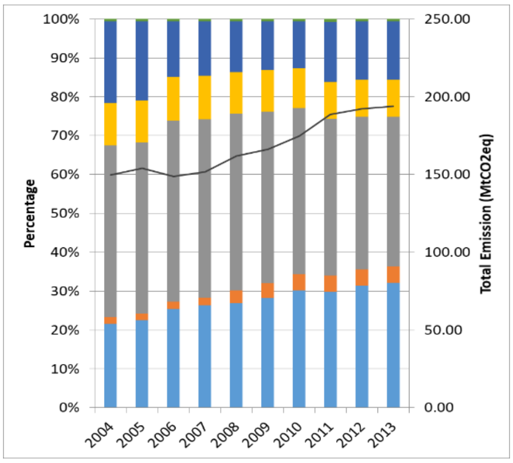
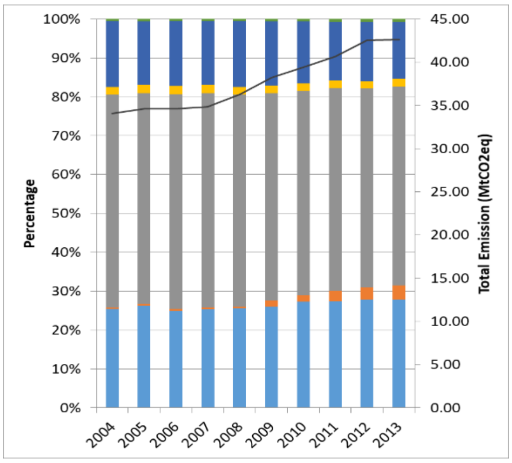


Figure 6. GHG inventory of Group A for 10 years (2004-2013)

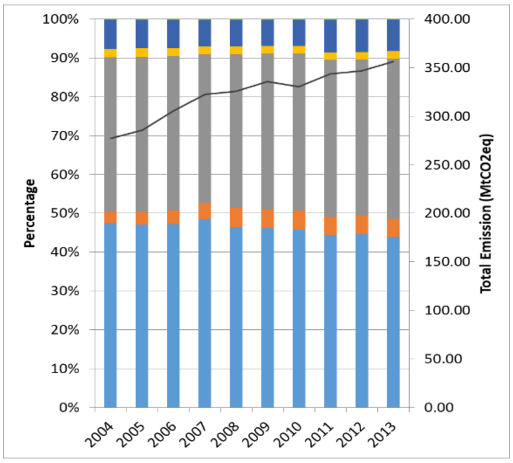
Sasaki (2006) reported Cambodia has lost about 2.5 million hectare that annually about 0.7% over 30 years from 1970s as a result of deforestation and logging. Furthermore, Murdiyarso and Lebel (2007); Verchot et al. (2010) have pointed out that the deforestation mainly played due to peat fire in Southeast Asia including Indonesia, through stopping land fires however, LUCF sector could be reduction opportunities.



(a) Bangladesh



(b) Nepal



(c) Pakistan

Figure 7. GHG inventory of Group B for 10 years (2004-2013)

In case of Group B in 2013, emissions onto agriculture sector in Bangladesh, 38.41%; Nepal, 51.23% and Pakistan, 41.27% present a vast portion that are slightly higher (Bangladesh, 32.17% and Nepal, 27.82%) or similar (Pakistan, 43.87%) amount with energy sector, for reference, the ten-year average GHG emissions of agriculture sector are Bangladesh, 43.09%; Nepal, 48.68% and Pakistan, 40.01% respectively. Moreover, Group B generally indicates to emit less than 1% of total GHG emissions from bunker fuel during 2004 to 2013 (in average, Bangladesh, 0.65%; Nepal, 0.54 and Pakistan, 0.29%). Actually in Nepal, the emissions from LUCF were aberrantly higher in 2004 and 2005 despite LUCF sector during 2006 to 2013 maintained 5.8 to 6.5 MtonCO_2eq. The possible reason of inconsistency in the data is that there might be human errors such as data omission and/or data processing error when the national GHG data is calculated (Rypdal and Winiwarter 2001), therefore, we interpolated the correction value computed using trend line ($y=0.686x+5.5935$) instead of abstruse LUCF data in 2004 and 2005.

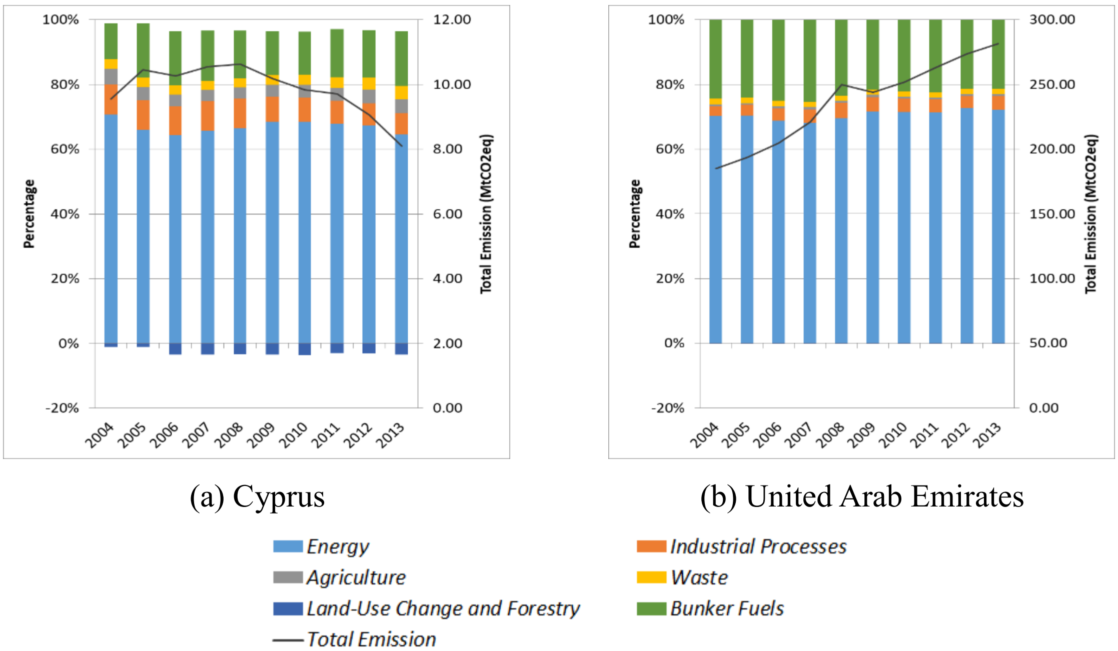


Figure 8. GHG inventory of Group C for 10 years (2004-2013)

Figure 8 shows GHG emission histories for Cyprus and United Arab Emirates (UAE) belonging Group C. Both countries mostly emit the greenhouse gas from energy sector that Cyprus, 71.20% and UAE, 70.75% as ten-year average. According to the previous studies, Cyprus and UAE are completely dependent more than 95% on the primary energy (Juaidi et al. 2016; Mirasgedis et al. 2004). Most of all, Mirasgedis et al. (2004) reported that Cyprus mostly uses heavy fuel among coal, crude oil, diesel, gasoline as well as any other liquid fuels, and the expected heavy fuel use would be continuously growing. For that reasons, the emissions from bunker fuel are comparably higher that Cyprus, 15.71±2.45% and UAE, 23.12±2.21% during

10 years, otherwise most of target countries have maintained no more than 5%. Additionally, Group C tends to be partially affected by energy sector emission although the emissions from other sectors have been constantly maintained during 2004 to 2013. For instance, total emission in Cyprus has been decreased due to the reduction of energy sector emission since 2008, on the other hand the total amount of emission in UAE has been increased because of the emission growth of energy sector.

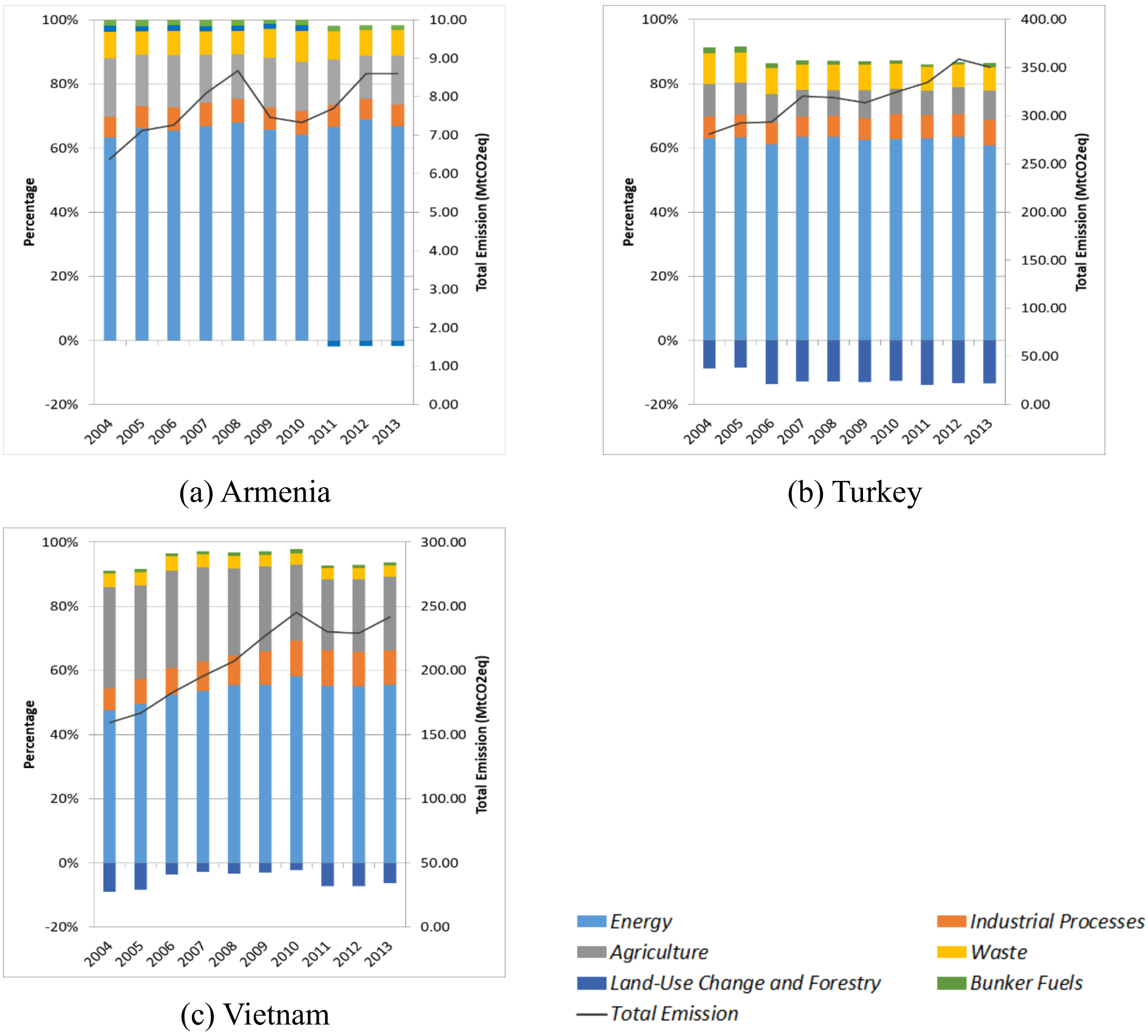
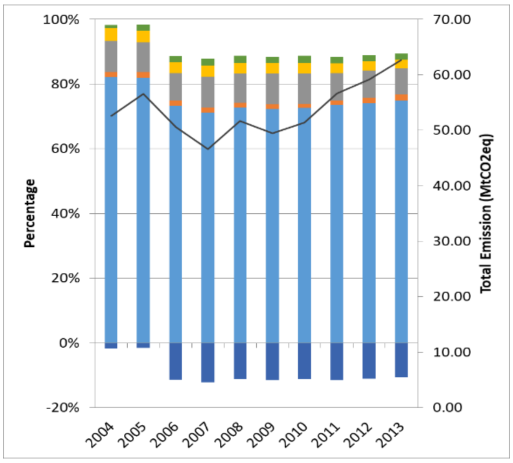


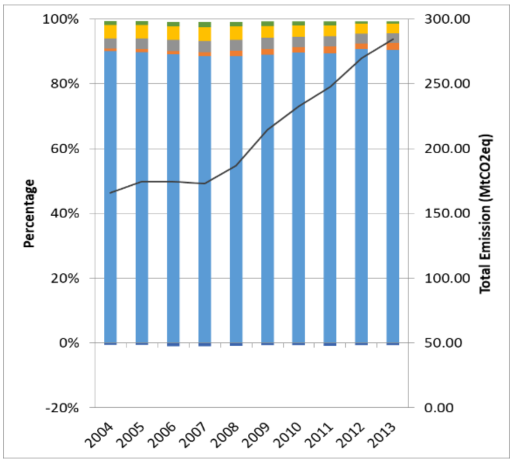
Figure 9. GHG inventory of Group D for 10 years (2004-2013)

Group D, similar to Group C, also have emitted more than half of the total emissions from energy sector, however, those countries have generally higher percentage of emissions on agriculture sector (Armenia, 15.50%; Turkey, 11.52% and Vietnam, 29.82%) rather than group C. All the countries in Group D have the negative quantities onto LUCF (Armenia, -1.75%; Turkey, -18.51% and Vietnam, -7.31%) in 2013, especially Turkey captures the vastest carbons (in average 53Mton CO_2eq for 10 years) through LUCF among 24 countries in this study. Overall, even though Armenia, Turkey and Vietnam steadily maintain their emissions on agriculture, waste and bunker fuel sectors for 10 years, the total emissions have been continuously increasing due to the growth of energy and agriculture sector.



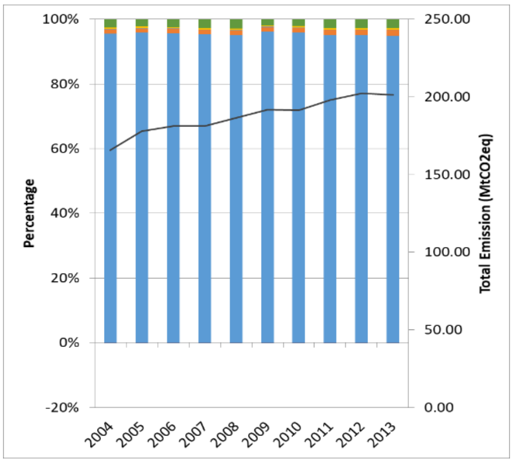
(a) Azerbaijan

(b) Brunei

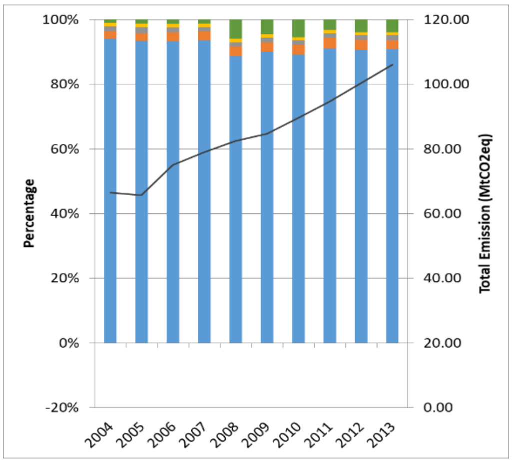


(c) Iraq

(d) Kazakhstan



(e) Kuwait

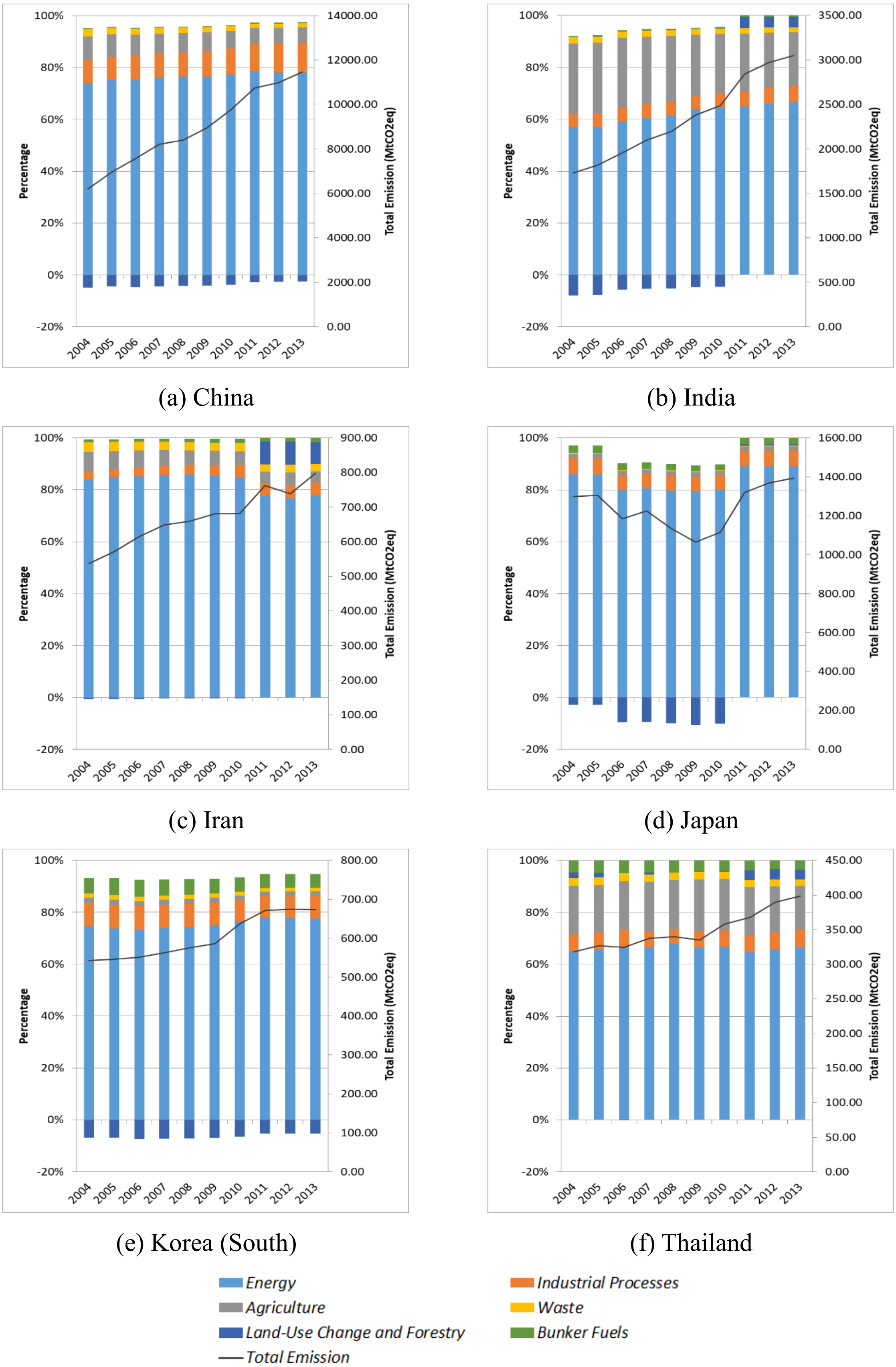


(f) Oman

Energy *Industrial Processes*
Agriculture *Waste*
Land-Use Change and Forestry *Bunker Fuels*
Total Emission

Figure 10. GHG inventory of Group E for 10 years (2004-2013)

Group E definitely emits the most of greenhouse gas through energy sector (averagely, Azerbaijan, 92.60%; Brunei, 87.68%; Iraq, 90.92%; Kazakhstan, 88.72%; Kuwait, 95.44% and Oman, 91.46) in contrast, industrial process sector (averagely, Azerbaijan, 1.94%; Brunei, 0.99%; Iraq, 1.54%; Kazakhstan, 1.38%; Kuwait, 1.41% and Oman, 2.58) is comparably less than other groups. Remarkably, Brunei showed different aspect with the other countries in Group E until 2010 and slightly changed due to reduction of LUCF emission, whereas the energy sector had increased. Iraq, Kazakhstan and Oman indicated a great deal of emission growth during the analyzed period due to the rapidly increasing energy sector for 10 years. Abdul-Wahab et al. (2015) has found that as Oman have started producing their own liquid fossil fuel and natural gas, the carbon emissions in Oman have drastically increased as a result of combustion petroleum refined products, according to analyzing energy sector associated-carbon emission trend from 1972 to 2013.



(a) China

(b) India

(c) Iran

(d) Japan

(e) Korea (South)

(f) Thailand

Figure 11. GHG inventory of Group F for 10 years (2004-2013)

In Figure 11, Group F demonstrates also the vast of emissions from energy sector (China, 82.93%; India, 67.2%; Iran, 83.7%; Japan, 94.92%; South Korea, 86.81% and Thailand, 66.18% as ten-year average). Particularly, most of countries in Group F have comparably higher portion of GHG emissions from industrial sector that China, 10.71%; India, 6.17%; Japan, 6.71; South Korea, 10.02% and Thailand, 6.42%. GHG emissions of China are significantly high since the large population, the heavy reliance on coal and fossil fuel as well as inefficient capital investment and urbanization (Mohajan 2013). Not only Asian region, but also the global village mainly use coal for producing more than 40 per cent of electricity for example South Africa (93%), China (79%), India (69%) and the United States (49%) (Van der Hoeven 2012). In case of China, India, Japan and South Korea, the carbon emissions from iron and steel industry related to fossil fuel combustion have the large portions onto industrial process sector (Gielen and Moriguchi 2002; Kim and Worrell 2002; Oh et al. 2010). Furthermore, India and Thailand have the massive fraction of agriculture sector that both countries mostly emit through energy, industrial process as well as agriculture sectors. Overall, even though 6 countries were assigned to one single group with some connections, more specifically, China and South Korea, India and Thailand, Iran and Japan have higher similarity according to cluster dendrogram as depicted in Figure 5.

3.4 Discussion

Cluster analysis suggested to establish GHG emission boundary in this study was appropriate for assigning 6 clustered groups, because we could highlight that each clustered group respectively has major and minor emission sectors among energy, industrial process, agriculture, waste, land-use change and forestry (LUCF) as well as bunker fuel as summarized in Table 6. Furthermore, the relation between topographical characteristics and climate (*e.g.* tropical-, temperate- and dry climate) that probably influence carbon emission can also be considered for more discussion following our research outcome.

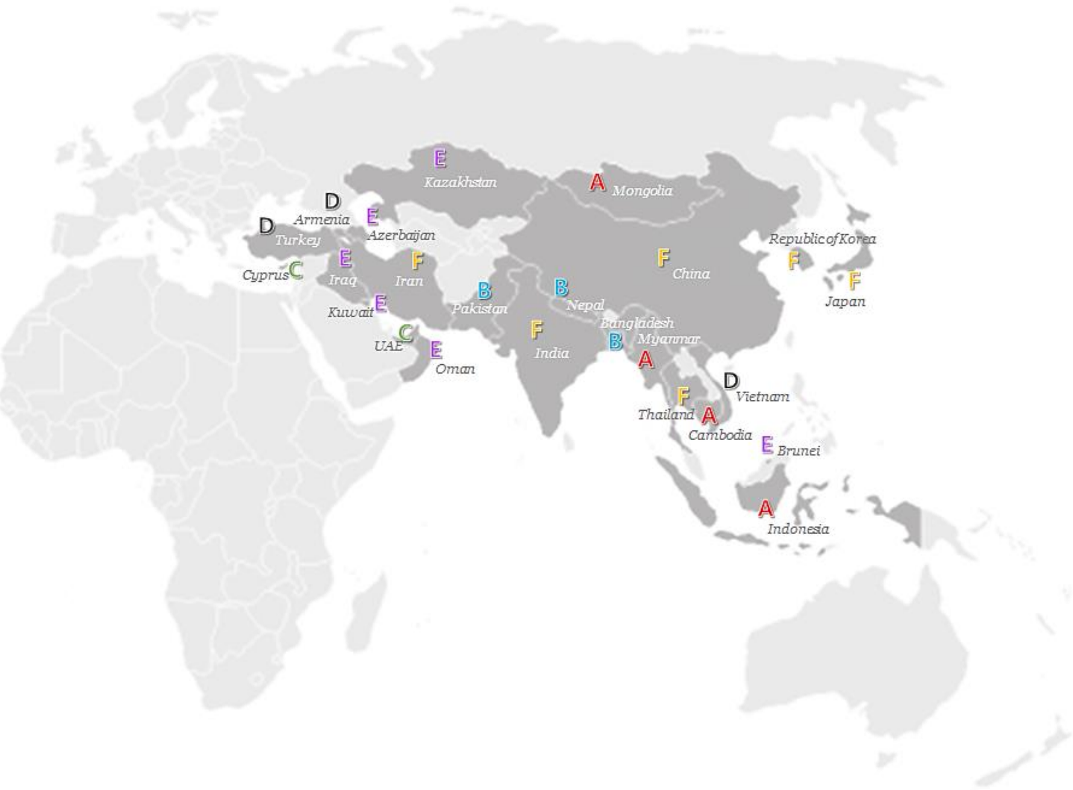


Figure 12. Geographically marked as clustered group

Table 6. Overall perspectives for analyzed clustering group

	Clustered countries	Major emissions sectors	Minor emissions sectors	LUCF value
Group A	Cambodia Indonesia Mongolia Myanmar	LUCF Agriculture	Industrial process Waste Bunker fuel	Positive quantity
Group B	Bangladesh Nepal Pakistan	Agriculture	Bunker fuel	Positive quantity
Group C	Cyprus UAE	Energy Bunker fuel	Agriculture	Negative quantity
Group D	Armenia Turkey Vietnam	Energy Agriculture Waste	Bunker fuel	Negative quantity
Group E	Azerbaijan Brunei Iraq Kazakhstan Kuwait Oman	Energy	Industrial process Waste Bunker fuel	Negative quantity (except Brunei)
Group F	China India Iran Japan Korea (South) Thailand	Energy Industrial process Agriculture (only India and Thailand)	Waste	Negative quantity (except Iran and Thailand)

According to Table 6 that the key solution of this research, Group A mostly emits GHGs through LUCF and agriculture sector, whereas rarely emits from industrial process. As Xiao et al. (2006) reported, rice agriculture in South and Southeast Asia, including countries in Group A provide a tremendous amount of harvest over a wide range of cropland area with diverse climatic conditions. Due to the great dependence of their economy on crop agriculture, large emission from agriculture sector would be continuously sustained. Furthermore, Dagvadorj et al. (2009) pointed field burning and traditional animal husbandry can be a major GHGs emission source in Mongolia. Consequentially, crop cultivation and livestock farming performed by economic dependence, climatic environment and long tradition lead higher emission from LUCF and agriculture sectors.

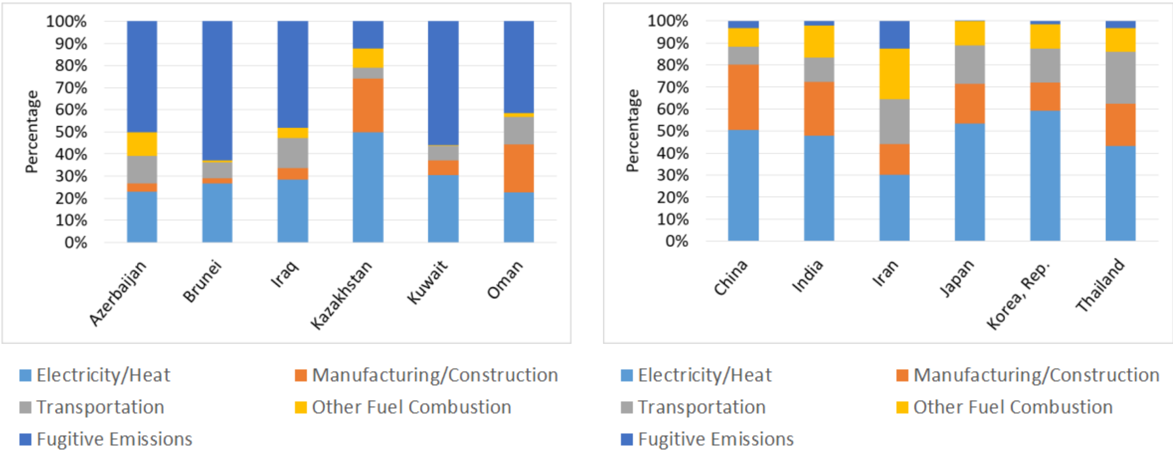
Group B has the vastest emission from agriculture sector and its growth rate is similar or more rapid than energy sector. Because all the countries in Group B significantly rely on agricultural production for their economic contributions (Shrestha and Aryal 2011; Sultana et al. 2009; Yu et al. 2010), GHG emissions from agriculture sector deservedly stands out as among the most sizable emission sector. Moreover, as a number of research articles investigated the economic impacts of climate change on crop agriculture and cultivation in developing countries (Chang 2002; Guiteras 2009; Kurukulasuriya and Ajwad 2007; Lansigan et al. 2000; Wang et al. 2009), effective management and climate strategy focused on agriculture production should be needed for both GHG emission reductions, food security. Difference between Group A and B would be LUFC emission sector possibly caused from shifting cultivation, tropical deforestation and clearing of secondary vegetation (Fearnside 2000; Miles and Kapos 2008).

Bunker fuel emissions were highlighted in Group C unlike the other countries, due to large usage of maritime shipping and power generation (Bensassi et al. 2011). However, although we infer from Rodoulis (2010) that marine aviation and shipping led by geographic position (*e.g.* island or sea-girt county) can be a potential comprehension to increase bunker fuel emissions, implication from higher bunker fuel emission aspect in Group C was not sufficiently accessible due to the lack of information.

Group D has large emissions from energy, agriculture and waste sectors. Moreover, Turkey and Vietnam hold comparably large amount of carbons through LUCF stock. Waste sector in Group D has turned out as one of the major emission sources unlike the other groups in particular Turkey. Because they are reliant on the energy importing, Turkish government has tried to increase the supply of renewable energy especially through the waste incineration and digester of animal waste (Yuksel and Kaygusuz 2011), as a result waste sector is responsible for relatively higher emission source.

Group E overwhelmingly generates GHGs from energy sector otherwise, industrial process, waste and bunker fuel sectors are extremely little. Solanki et al. (2013) reported that Oman and Kuwait well known as Gulf cooperation council (GCC) states cover most of their domestic energy consumptions from fossil fuel, that finally plays an important role to contribute higher emissions from energy sector. Furthermore, tax-free regulations as well as subsidized electricity and energy will be one of the understandings that energy sector is the most dominant GHG emission source in GCC countries and other oil-producing countries (Qader 2009).

Group F similarly have massive portion onto energy sector, but contrary to Group E, a chunk of industrial process sector occupies due to energy intensive manufacturing process (*e.g.* cement, iron and steel industry). In addition, although both groups that Group E and Group F emit large amount of greenhouse gas onto energy sector, they indicate different emission properties according to the energy subsector data in Figure 13.



(a) Energy subsector of Group E (b) Energy subsector of Group F

Figure 13. GHG emission energy subsector of Group E and Group F in 2013

Energy sector covers five different subsectors in this paper that electricity and heat, manufacturing and construction, transportation, other fuel combustion as well as fugitive emissions. In Group E, more than 40% of energy subsector is occupied by fugitive emissions only except Kazakhstan on the other hand, Group F mostly emits GHGs from electric/heat and manufacturing/construction. Hence, multidirectional inquiry for more specific diagnosis is indispensable, in spite of the ostensible appearances are analogous such as Group E and Group F.

Then, which implication can be drawn from the result in this study? Most of all, our attempt to investigate GHG emission history and assign possible groups on the basis of emission characteristics *e.g.* major and minor emission sectors as well as the play of LUCF would be a beneficial knowledge to develop further implementations. Subsequently, effective climate actions and verified best practices should be taken considering clustering result to follow up the outcome of this paper. For instance, carbon reduction technologies, particularly in energy intensive manufacturing process such as cement, iron and steel industries can be applied and allow between 10 and 20 % of energy efficiency enhancement in large amount of energy consuming countries such as China, India, Japan and South Korea (Garg et al. 2017; Kim and Worrell 2002; Kuramochi 2016; Lee et al. 2016; Zhang et al. 2017). Adapting carbon footprint (CF) assessment and effective farm management during farm production (crops, fertilizer, farm production, forage feeding and manure treatment) and consumption (sales and distribution system as well as home dining) are also applicable for food security and climate change mitigation especially in agricultural-economic based developing countries. Protection of forests through reducing deforestation and illegally over-logging is significant particularly in large amount of LUCF emitting countries (*e.g.* Group A) because forests play a greatly important role for carbon sink by themselves. Thus, further framework for climate change response can be suggested following the research outcome as summarized in Figure 14.

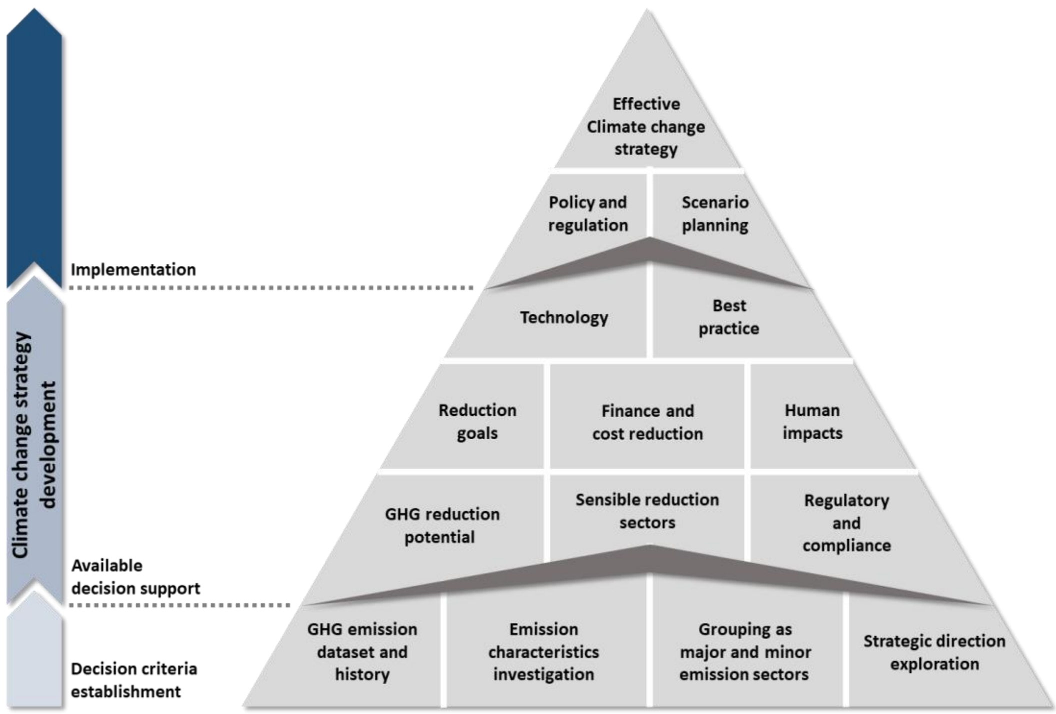


Figure 14. Further development framework for climate change strategy

4. CONCLUSION

This study explored the greenhouse gas emission information in 24 Asian countries on the basis of national GHG inventory data during the ten years of period between 2004 and 2013. In spite of the minuscule amount of potential inaccuracies and inconsistencies in CAIT data, it was interesting to remark that assigning 6 clustered groups respectively have GHG emission characteristics *i.e.* major and minor GHG emission sectors. As adapting one of hierarchical clustering techniques that complete linkage method, it was meaningful to present our approach for establishing boundaries of GHG emission features across certain Asian countries. Therefore, the result of this study can provide fundamental reference to develop further climate mitigation strategies.

Furthermore, the research outcome can be adapted as future directions and decision criteria that determining practical reduction sectors, calculating the amount of carbon reduction potential and considering best practice, technology, appropriate policy and regulatory framework to establish climate change strategies corresponding to each clustered groups. Thus, we expect that this innovative approach for clarify emission attributes would be useful to policy makers, environmental scientists, decision makers as well as planners for extending further implementation at the local government, national and regional levels.

Although we present GHG emission analysis and suitable clustered groups, some of national GHG inventory data were omitted or not sufficiently built due to the different possible errors. As implied in Figure 14, it is significant to establish well-organized framework for further development and improvement of climate change mitigation strategy. Hence, more accurate and reliable GHG emission information should be established for effective approach to climate change implementation. Overall, the first step of entirely reviewing the wide range of GHG emission histories and sectoral GHG emission properties would be beneficial to develop reduction potential in Asian region as a guideline. At the same time, further study for evaluating specific reduction in the amount of carbon and improving climate change mitigation strategy is to be carried out to successfully drive and manage the forthcoming achievement for human well-being and sustainable societies in Asia.

5. ACKNOWLEDGEMENT

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