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Comparative analysis of greenhouse gas emission inventory for Pakistan: Part I energy and industrial processes and product use

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Abstract

In order to further improve the accuracy and reliability and reduce uncertainties in the national GHG inventories for Pakistan, this study call for using 2006 IPCC Guidelines, to help to identify the national targets for GHG mitigation with respect to the nationally determined contributions (NDCs). GHG (CO_2, CH_4, and N_2O) inventories for Pakistan have been developed by conducting a detailed sectoral assessment of IPCC source sectors, energy, industrial processes and product use (IPPU), agriculture, forestry and other land use (AFOLU), and the waste sector. Further, sector wise comparative analysis of GHG inventories (1994−2017) based on the 2006 and 1996 IPCC Guidelines have also been presented. Results indicated an average relative difference of 4% in total GHG emissions (CO_2 equivalent) from energy sector between 2006 and 1996 IPCC Guidelines. With 3.6% average annual growth rate based on 2006 IPCC Guidelines, CO_2 from energy sector remained the most abundant GHG emitted, followed by CH_4 and N_2O. While the average absolute difference in emissions of CH_4 and N_2O from the energy sector is notable, the total estimated GHG emissions by 2006 IPCC Guidelines duplicate those by 1996 IPCC Guidelines. In the mineral industry with 2006 IPCC Guidelines, an average annual growth rate of 6.7% is observed, contributing 64% of total IPPU sector CO_2 emissions. Nevertheless, the relative difference between the two Guidelines in overall IPPU sector emissions remained negligible. There might be a need for switching to 2006 IPCC Guidelines to consider more parameters such as additional source sectors and new default emission factors that fit into national circumstances.

Keywords: Greenhouse gas; Emission inventory; Energy sector; Industrial processes and product use; Pakistan

1. Introduction

Implementation of the Paris Agreement (UNFCCC, 2015) requires all parties to report their national anthropogenic greenhouse gas (GHG) emissions to the United Nations Framework Convention on Climate Change (UNFCCC) on a regular basis and to frequently analyze the sum of global emissions in the process of global stocktaking (UN, 1992; UNFCCC, 2015). An essential part of the Paris Agreement is the transparency framework, to ensure accurate, transparent, comparable, consistent and complete reporting of GHG inventories, building on the methodologies developed by the Intergovernmental Panel on Climate Change (IPCC) (Bergamaschi et al., 2018). Reporting for non-Annex I Parties to the UNFCCC is implemented through national communications (NCs) and biennial update reports (BURs), subject to the availability of financial support (Zhu and

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Wang, 2013). The Government of Pakistan submitted its Initial National Communication (Pak-INC) (UNFCCC, 2003a) to the UNFCCC on November 15, 2003 and Second National Communication (Pak-SNC) (UNFCCC, 2019a) on August 9, 2019 with national GHG inventories for the years 1994 (UNFCCC, 2003a) and 2015 (GCISC, 2017), respectively. These two inventories were prepared following the Revised 1996 IPCC Guidelines for National GHG Inventories (hereinafter referred to as 1996 GLs) (IPCC, 1997). Moreover, GHG inventories for the years 2008 (ASAD, 2016), and 2012 (GCISC, 2016; Mir et al., 2017) have also been completed in indigenous capacities using the same 1996 GLs. Nevertheless, since the publication of 2006 IPCC Guidelines for National GHG Inventories (hereinafter referred to as 2006 GLs) (IPCC, 2006), UNFCCC Decision 24/CP.19 (UNFCCC, 2014) required Annex I parties only to use 2006 GLs, implying that non-Annex I parties were not obliged to apply 2006 GLs (Yona, 2020). Therefore, non-Annex I parties were mostly using the 1996 GLs in accordance with the UNFCCC Decision 17/CP.8 (UNFCCC, 2003b). On the other hand, the recent UNFCCC Decision 18/CMA.1 under Katowice climate package (UNFCCC, 2019b) stipulates that each party shall use the 2006 GLs with regard to methodologies, parameters, and data. Pakistan should therefore make every effort to prepare its national GHG inventories using the latest 2006 GLs. Further, the 2006 GLs have several advantages over the 1996 GLs in terms of additional sources, new default emission factors, guidance on choosing appropriate estimation methods for individual inventory categories, and cross-sectoral good practice guidance e.g. key category analysis to identify most important inventory categories (Breidenich, 2011). It might at first result in facing the challenge of modifying Pakistan's nationally determined contributions (NDCs) (UNFCCC, 2016) in line with the new inventories estimates.

With the exception of ASAD (2009), the 2006 GLs have never been implemented for calculating national GHG emissions in Pakistan. In addition, neither higher Tiers nor country-specific parameters were used or identified in Pak-INC and Pak-SNC, the default approach (Tier 1) was applied in both inventories by using 1996 GLs (UNFCCC, 2003a, 2019; GCISC, 2017). There is an urgent need of at least shifting to 2006 GLs which might consider more parameters (e.g. additional source sectors, new default emission factors) that fit into national circumstances and reduce the uncertainty of GHG emissions estimates. This study deals with a more technical, improved, and comprehensive time series (1994−2017) evaluation of Pakistan's GHG emissions inventories using the latest 2006 GLs and their comparison with those prepared following the old 1996 GLs. This would provide an insight into: the difference in GHG emission quantities between both GLs; the mitigation priorities that need to be considered in future; and the importance of applicability of 2006 GLs which has been hardly recognized by developing countries.

2. Methods and data

2.1. Data sources

The activity data used was acquired from official national government documents such as: Pakistan Energy Year Book by the Hydrocarbon Development Institute of Pakistan (HDIP, 1994, 2008, 2012, 2015, 2017), Pakistan Economic Survey by the Ministry of Finance (MoF, 2008, 2012, 2015, 2017), Pakistan Agricultural Statistics by the Ministry of National Food Security and Research (MoNFSR, 2019), Industrial Statistics from the Ministry of Industries and Production Year Book (MoIP, 2017); and Pakistan Forest Resources Assessment (FAO, 2015) by the Ministry of Climate Change. In addition, country specific information from a few international sources such as the Food and Agriculture Organization (FAO), the World Bank (WB), the United States Geological Survey (USGS), and the United Nations (UN) was also accessed.

At the time of current study, the GHG inventories data estimated by UNFCCC Non-Annex I National Greenhouse Gas Inventory Software for four years (1994, 2008, 2012, and 2015) based on the Tier 1 approach in the 1996 GLs, was available (UNFCCC, 2003a; ASAD, 2009, 2016; GCISC, 2016, 2017; Mir et al., 2017). In addition, Pakistan's latest GHG inventory (2017) was estimated as part of the present work using the same 1996 GLs methodology and data sources as used in previously available inventories to maintain the consistency. Following the 1996 GLs, the source sectors included in all these five-year (1994, 2008, 2012, 2015, and 2017) GHG inventories were energy, industrial processes, agriculture, land use change and forestry (LUCF), and waste. The linear statistical interpolation method was then applied to the detailed data points of the five-year inventories at the national, sectoral, and sub-sectoral levels to develop the estimates for the missing intermediate years. This completed the development of time series (1994−2017) of the estimates based on the 1996 GLs. The year 1994 was considered as the base year and 2017 as the latest year. The same data points of the five-year inventories were then updated and estimated following the latest 2006 GLs together with the corresponding sectoral worksheets by considering same source sectors, method, and data.

2.2. Emission estimation

In general, both sets of GLs follow the same methodological approach (IPCC, 1997, 2006). This approach involves integrating information on the level of human activity, known as Activity Data, with the quantified emission coefficients per unit activity, known as the Emission Factor. Therefore, the fundamental equation that was used to calculate the GHG emissions from different source sectors is: Emissions = Activity Data × Emission Factor. Although the country-specific sectoral activity data for multiple years based on national official statistics have been used, all the emission factors were the default values provided by both the 1996 and 2006 GLs. The simplest Tier 1 sectoral approach, typically requiring the most basic and least disaggregated activity details along with the default emission factors of IPCC, was used to calculate the emissions of three GHGs, CO_2, CH_4, and N_2O.

2.3. Missing data management

According to the IPCC GLs, the national GHG inventories must be recorded in the calendar year in which the atmospheric emissions occur (IPCC, 2006). Nonetheless, if the unavailability of sufficient data prevents compliance with this rule, emissions can be calculated using information from other years by applying reasonable splicing techniques such as overlapping, surrogate approach, interpolation, and trend extrapolation to complete the time series (IPCC, 2006). In this analysis, since the inventories information from 1994 to 2017 were available for five distinct years (1994, 2008, 2012, 2015, and 2017), the data for the missing intermediate years were interpolated linearly to complete the time series. This method seems practical as the overall trend tended to be stable, and real emissions for missing intermediate years are unlikely to vary significantly from the predicted interpolation values.

3. Time series GHG inventories using 2006 GLs

3.1. Energy sector

Two versions of the CO_2 emissions of the energy sector exist: the Sectoral Approach and the Reference Approach. Under the convention, the Sectoral Approach is used for inventory development whereas the Reference Approach is used for verification purposes only (quality control activity). The Sectoral Approach is based on data collected from the Pakistan Energy Year Book (HDIP, 1994, 2008, 2012, 2015, 2017) and additional source-specific information. The Sectoral Approach combines fossil fuel consumption statistics with bottom-up information and calculations based on fuel consumption models. On the other hand, the Reference Approach employs a top-down strategy based on the apparent consumption of energy by Pakistan as reflected in the energy production statistics of the Pakistan Energy Year Book. Within the dataset, the differences in energy consumption and CO_2 emissions between Reference Approach and Sectoral Approach are determined. For both methods, the CO_2 emissions and difference in energy consumption are below 5% for the entire period and do not need any clarification according to the 2006 GLs. In addition, the default 100% oxidation rate for various types of fuel combustion is used in the new 2006 GLs based inventories compared to the old 1996 GLs based, where the default oxidation rate used for coal, natural gas, and oil was 98%, 99.5%, and 99%, respectively.

The energy sector is the most important source of GHG emissions in Pakistan. The CO_2 produced by the energy sector is the most abundant GHG released into the atmosphere, followed by CH_4 and N_2O (Fig. 1a), with an average annual growth rate of 3.6%. With the exception of a marked increase between 2015 and 2017 owing to a substantial increase in the amount of energy consumed by new power plants for electricity generation, GHG emissions from the energy sector continued to expand over the period examined. The almost flat pattern in the period 2008−2012 is the result of the energy crises in Pakistan. The main types covered by the energy sector are fuel combustion and fugitive emissions from fuels. Four source categories dominate the GHG emissions in Pakistan's energy sector. The energy industries (mainly electricity generation) and manufacturing industries are the primary sources of GHG emissions (Fig. 1b). Transport (mainly road transport) and other sectors (commercial, residential, and agriculture) also play an important role in national GHG emissions.

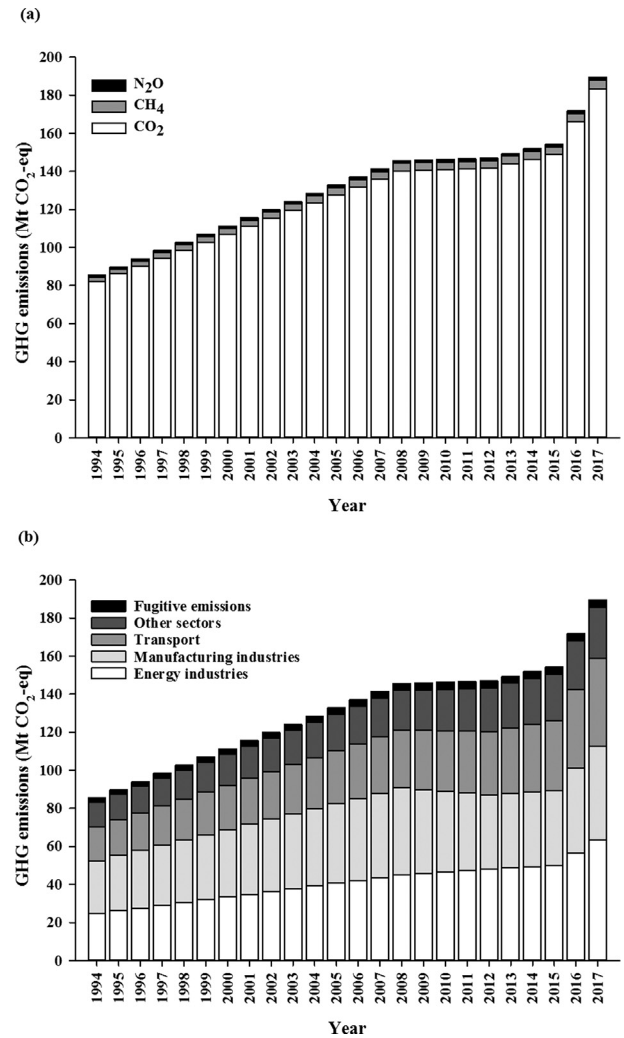

Fig. 1. GHG emissions from the energy sector of Pakistan using 2006 GLs during 1994−2017 by gas (a), and by sub-sector (b).

3.1.1. Fuel combustion

The fuel combustion sub-sector constitutes, among other sub-sectors (fugitive emissions), the largest share representing more than 97% of total emissions from the energy sector. Combustion activities include both stationary and mobile combustion operations that represent almost all combustion

Table 1
GHG emissions from the energy sector of Pakistan for 1994−2017 (2006 GLs) (unit: Mt CO_2-eq).

Year	Fuel combustion								Fugitive emissions			Total[d] (A + B)
	Energy industries		Manufacturing industries	Transport			Other sectors[b]	Total (A)	Coal mining	Oil & natural gas	Total (B)	
	Electricity generation	Other energy industries[a]		Road	Domestic aviation	Rail & other						
1994	22.07	2.74	27.67	15.91	1.34	0.66	12.92	83.31	1.03	1.20	2.23	85.54
1995	23.48	2.79	28.96	16.71	1.37	0.72	13.47	87.50	1.04	1.29	2.33	89.83
1996	24.89	2.83	30.25	17.50	1.40	0.78	14.03	91.69	1.05	1.39	2.44	94.13
1997	26.29	2.88	31.54	18.30	1.44	0.85	14.58	95.87	1.07	1.49	2.55	98.42
1998	27.70	2.92	32.83	19.09	1.47	0.91	15.14	100.06	1.08	1.58	2.66	102.72
1999	29.11	2.97	34.12	19.89	1.51	0.97	15.69	104.24	1.09	1.68	2.77	107.01
2000	30.52	3.01	35.40	20.68	1.54	1.03	16.24	108.43	1.10	1.77	2.87	111.31
2001	31.93	3.06	36.69	21.47	1.57	1.09	16.80	112.62	1.11	1.87	2.98	115.60
2002	33.34	3.10	37.98	22.27	1.61	1.15	17.35	116.80	1.13	1.97	3.09	119.89
2003	34.74	3.15	39.27	23.06	1.64	1.22	17.91	120.99	1.14	2.06	3.20	124.19
2004	36.15	3.19	40.56	23.86	1.67	1.28	18.46	125.18	1.15	2.16	3.31	128.48
2005	37.56	3.24	41.85	24.65	1.71	1.34	19.02	129.36	1.16	2.25	3.41	132.78
2006	38.97	3.28	43.14	25.45	1.74	1.40	19.57	133.55	1.17	2.35	3.52	137.07
2007	40.38	3.33	44.42	26.24	1.77	1.46	20.12	137.73	1.19	2.45	3.63	141.36
2008	41.79	3.38	45.71	27.04	1.81	1.53	20.68	141.92	1.20	2.54	3.74	145.66
2009	41.18	4.74	44.05	27.81	1.85	1.39	21.25	142.28	1.16	2.56	3.72	146.00
2010	40.58	6.10	42.39	28.58	1.90	1.25	21.83	142.64	1.12	2.58	3.71	146.35
2011	39.98	7.47	40.73	29.36	1.95	1.12	22.40	143.00	1.09	2.60	3.69	146.69
2012	39.38	8.83	39.07	30.13	1.99	0.98	22.97	143.36	1.05	2.63	3.68	147.03
2013	40.98	7.84	39.21	31.41	1.93	0.95	23.48	145.79	1.06	2.60	3.66	149.45
2014	42.59	6.85	39.34	32.68	1.87	0.92	23.99	148.22	1.06	2.58	3.65	151.87
2015	44.20	5.85	39.47	33.95	1.80	0.89	24.50	150.65	1.07	2.56	3.63	154.29
2016	46.11	10.66	44.40	38.58	1.91	0.98	25.59	168.21	1.13	2.63	3.76	171.97
2017	48.02	15.46	49.33	43.20	2.01	1.07	26.68	185.78	1.20	2.69	3.89	189.66
CAGR[c]	3.4%	7.8%	2.5%	4.4%	1.8%	2.1%	3.2%	3.5%	0.7%	3.6%	2.5%	3.5%

Note: [a] This includes fossil fuel combustion in petroleum refining and gas processing plants; [b] This includes fossil fuel combustion in the residential, commercial/institutional, and agricultural/forestry/fishing sectors; [c] CAGR is the compound annual growth rate, calculated by the formula (latest value/base value) $^{(1/\text{no. of years})}-1$; [d] May not sum similar to the total due to rounding.

activities in Pakistan. The fuel combustion sub-sector primarily comprises four categories, specifically the energy industries (power), manufacturing industries, transportation, and other sectors (commercial, residential, and agriculture). Table 1 provides a comprehensive overview of the amount of GHG emissions produced by the fuel combustion categories. The category of energy industries adds most of the GHG emissions of the energy sector, representing 31% of the total average GHG emissions of this sector. This is followed by the manufacturing industries, which contributed about 30%. The GHG emissions from the transport category and other sectors are lower than other categories and represented an average of about 21% and 15% of the total GHG emissions of the energy sector, respectively. The fugitive emissions have a significantly reduced share (3%) of the total national GHG emissions of Pakistan.

It is observed that the average annual growth rate of the GHG emissions (approximately 2.5%) is comparatively low for the manufacturing industries, despite this category being the second largest contributor to GHG emissions in the energy sector. The gas-consuming manufacturing industries include steel mills, cement, fertilizer (as consumers of fuel) and general industries in Pakistan. The major coal consumers in the manufacturing sector are the steel, cement, and brick kiln industries. In addition, the natural gas used in gas processing plants belonging to other energy industries (sub-sector of manufacturing of solid fuels and other energy industries) has the highest average annual growth rate of nearly 8%. Similar to the energy sector as a whole, CO_2 holds the largest amount and share of the GHG emissions in transport sector. Owing to the significant contribution of road transport (90% with an average annual growth rate of approximately 4.4%) the transport sector emissions increased by approximately 4.2% on average. The combined average annual growth rate for rail, navigation, and other transportation and domestic aviation was 2.1% and 1.8% respectively.

It is observed that all categories in the energy sector had a positive annual growth rate in GHG emissions during 1994−2017. This specifies the increase in fuel consumption in this sector due to increase in energy demand owing to urbanization, economic growth and population in Pakistan. The GHG emissions resulting from fuel combustion are mainly associated with the amount of fuel burned in respective sectors. The CO_2 emissions from these categories are determined on the basis of the fuel used by each sector and the carbon content of the fuel, irrespective of the combustion technology or emission control technology in use. The carbon content of fuel is relative to the default IPCC values, but for the purpose of calculating GHG emissions, the gross calorific value (GCV) is translated to the net calorific value (NCV) according to the 2006 GLs.

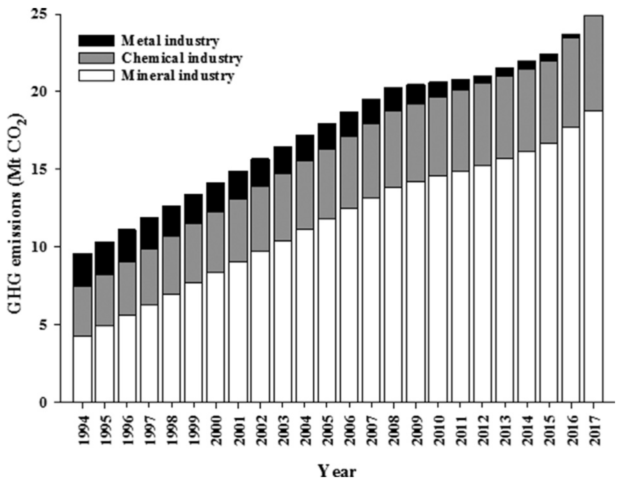

Fig. 2. GHG emissions from the industrial process and product use (IPPU) sector of Pakistan, during 1994–2017 using 2006 GLs.

3.1.2. Fugitive emission

This sub-sector consists of three sources of fugitive emissions (primarily CH_4), solid fuels, oil and gas systems, and other energy production. The first two categories of fugitive CH_4 emissions are estimated in this study. The total fugitive CH_4 emission constitutes 3% of the total GHG emission from the energy sector. However, an average annual growth rate of 2.5% is noted for fugitive CH_4 emissions, as shown in Table 1. The relatively small percentage of GHG released from this group is mainly because of Pakistan's lower production of oil, gas, and coal. There is, however, a significant difference between the estimates using the 2006 GLs and 1996 GLs, respectively, especially for fugitive CH_4 emissions from the production and distribution of natural gas. This distinction is attributable to the implementation of very high emission factors by using the 1996 GLs. Nevertheless, the emission factor of the 2006 GLs has been revised and has a reduced range relative to that of the 1996 GLs.

3.2. Industrial processes and product use

The industrial process and product use (IPPU) sector is the third largest contributor to total GHG emissions from Pakistan after the AFOLU sector. IPPU-emitted GHGs vary from other sectors as they consist of CO_2, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) (all from product use). Fluorinated GHG emissions (including

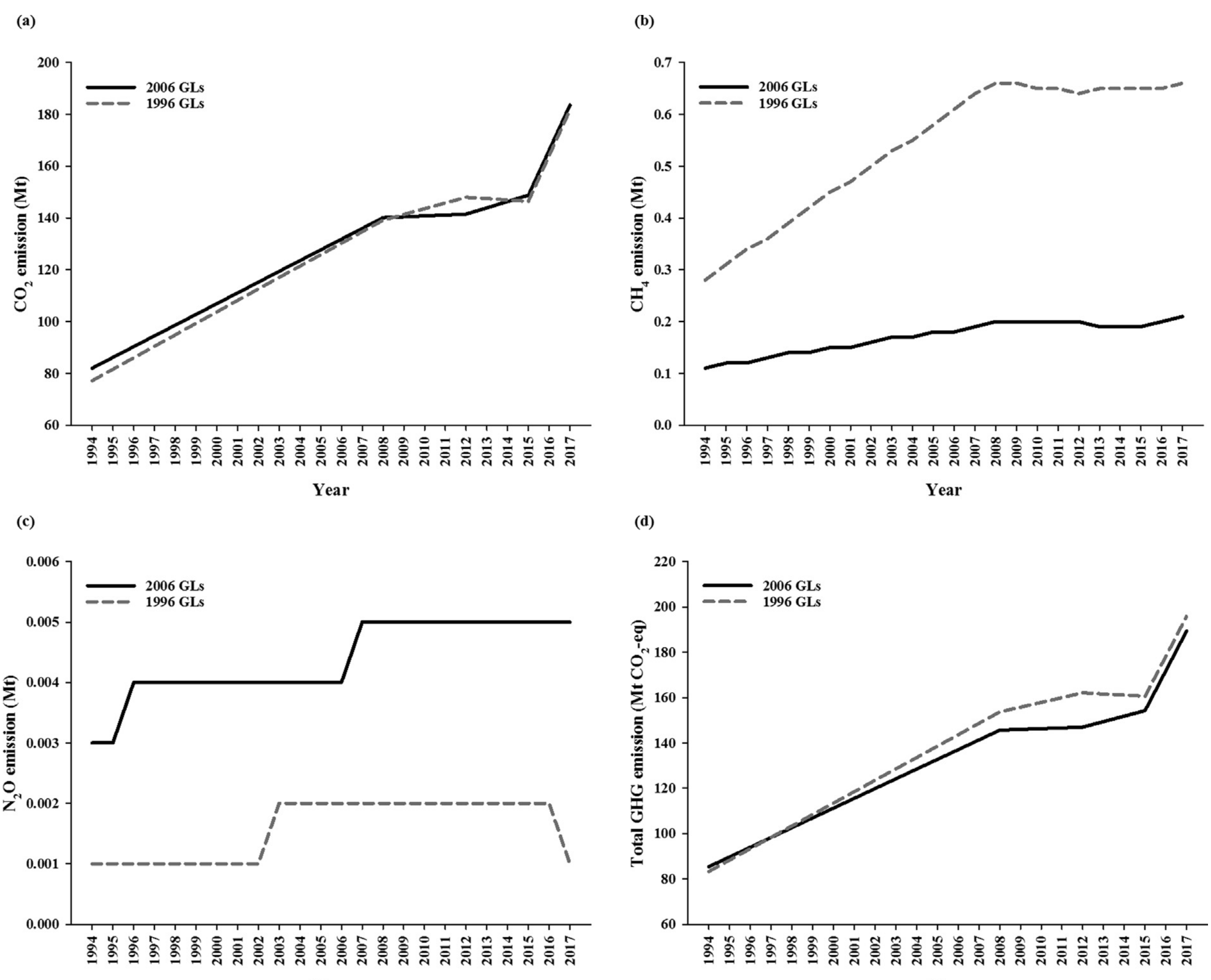

Fig. 3. Energy sector overall gap during 1994–2017 of (a) CO_2, (b) CH_4, (c) N_2O, and (d) CO_2-eq emissions in Pakistan 2006, vs. 1996 GLs.

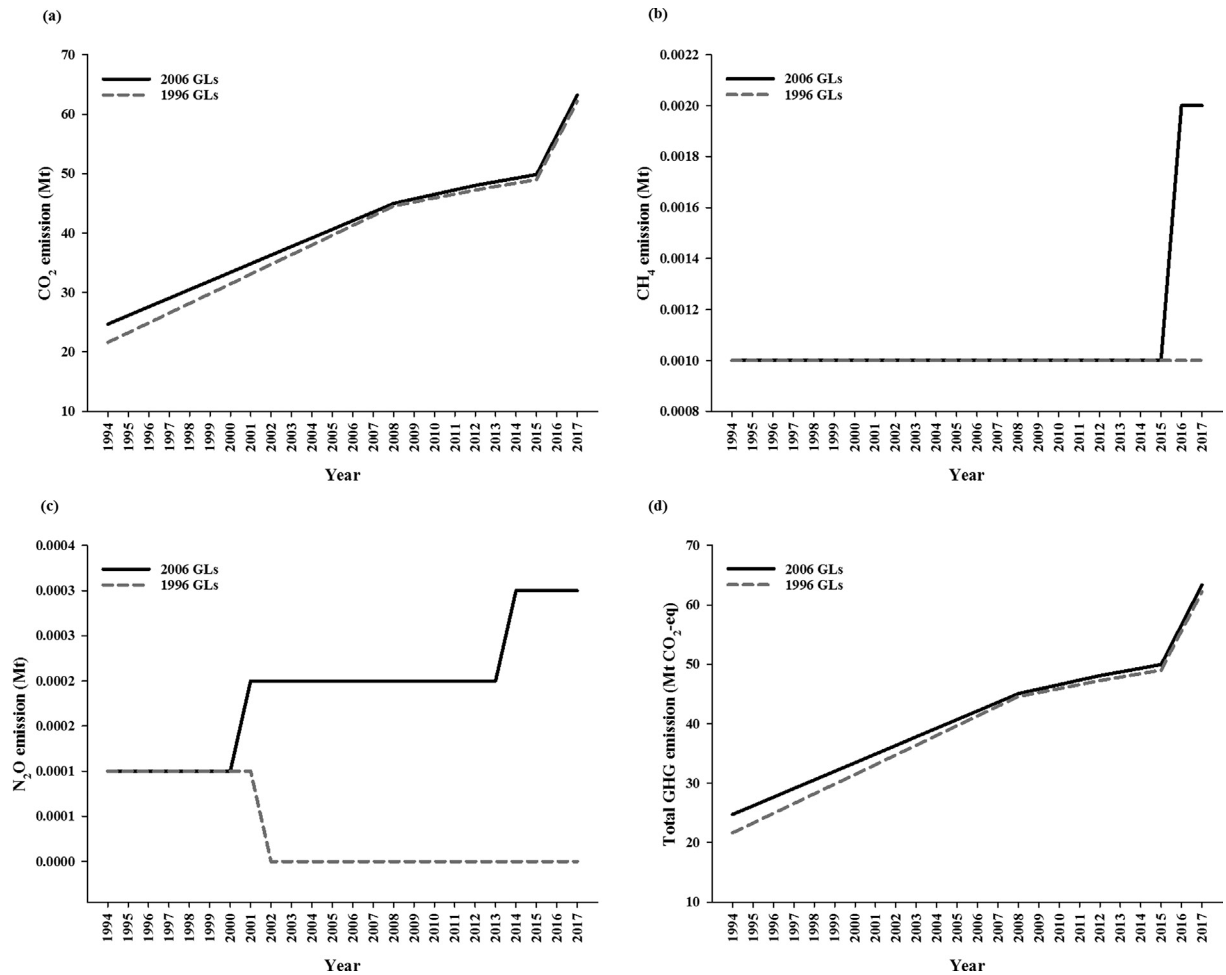

Fig. 4. Difference in GHG emissions in the energy industries in Pakistan during 1994−2017, 2006 vs. 1996 GLs.

HFCs, PFCs, and SF_6) have never been reported because of the lack of activity data in Pakistan. CO_2 emissions show a steady increase (average annual growth rate of 4.2%) throughout the time series as a result of continued growth in cement production in the mineral industry which is the primary contributor to industrial process emissions. The emissions from the IPPU sector are mainly from the mineral, chemical, and metal industries. Fig. 2 shows GHG emissions from the IPPU sector of Pakistan using 2006 GLs.

Table A1 provides an aggregate overview of GHG emissions from the IPPU sector and the percentage share. The largest average annual growth rate (6.7%) is observed in the mineral industry sub-sector, which mainly includes cement production. GHG emissions associated with imports and exports of clinker bricks is assumed to be zero in Pakistan as assumed in past national GHG inventories. The other category in the mineral industry is lime production, which forms 5% of the share of the mineral industry in this subsector. The remaining 95% is that of cement production. The proportion of limestone and dolomite extraction/production data (MoF, 2017) in Pakistan (mainly in the Pakistan's steel industry) remained the same (4% of limestone extraction/production; 73% of dolomite extraction/production) as in the Pak-INC inventory by assuming the fact that the capacity of Pakistan steel has not increased since 1994 and has remained constant. In the IPPU sector the overall share of the mineral industry is 64% followed by the chemical industry (27%).

Further 2006 GLs also require data regarding the mass of the lime (high-calcium lime and dolomite lime) produced rather than the mass of limestone or dolomite produced/extracted. Therefore, further calculation was carried out to convert limestone/dolomite ($CaCO_3$/$CaMg(CO_3)_2$) production/usage data into the mass of lime (high calcium lime and dolomite lime) produced by using the conversion factor given in the 2006 GLs i.e., 1 t of lime (CaO) requires the calcination of 1.785 t of $CaCO_3$. The Pakistan Economic Survey provides data on the production of soda ash rather than the use of soda ash, therefore the emissions from soda ash production are reported in the chemical industry according to the 2006 GLs, whereas emissions resulting from the use of soda ash are included in the respective end-use sectors in which soda ash is used. Thus, based on the availability of data, the chemical industry worksheet of 2006 GLs was used for CO_2 emissions from soda ash production. According to the 2006 GLs, soda ash emissions are included in the emissions

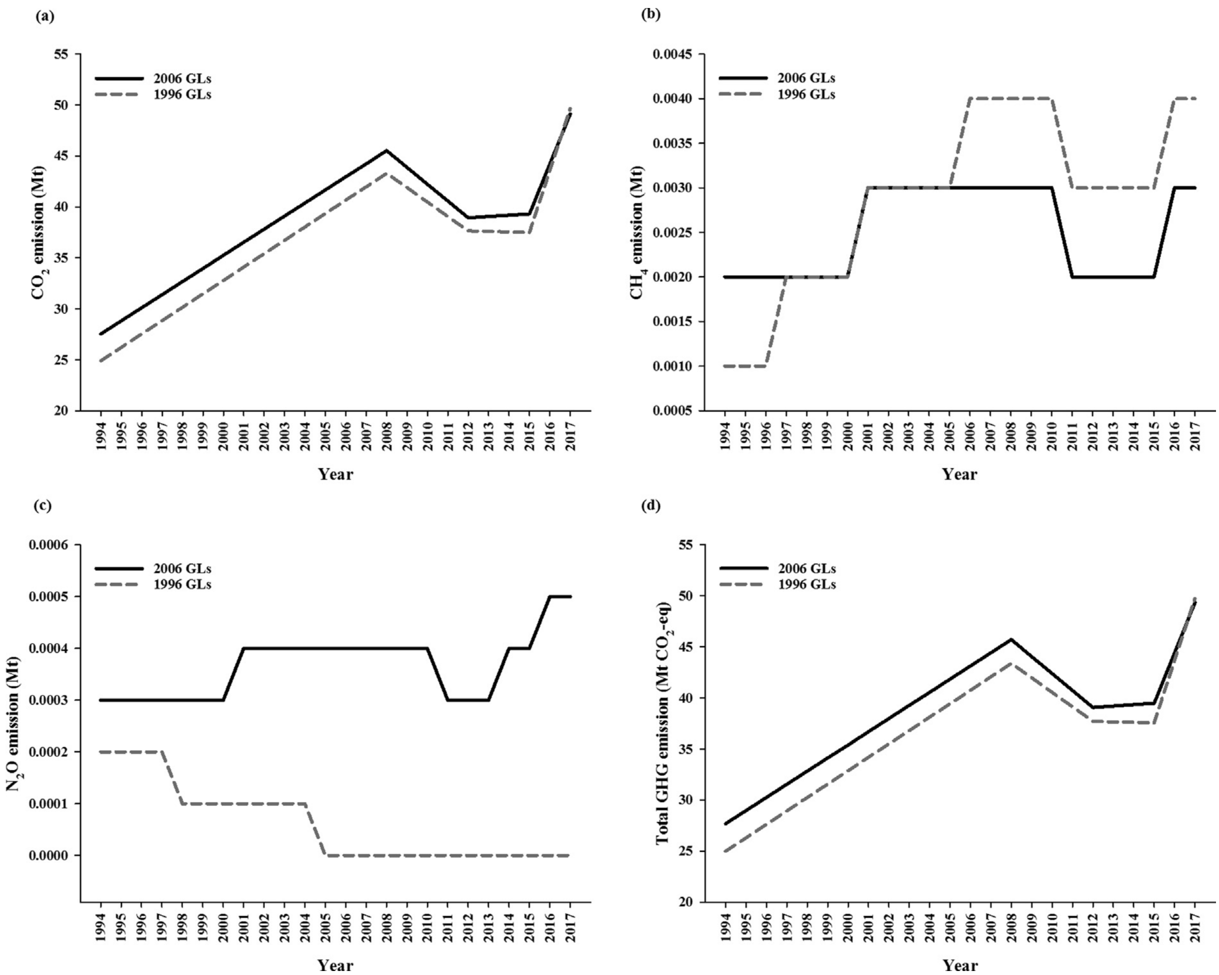

Fig. 5. Difference in GHG emissions in the manufacturing industries in Pakistan during 1994–2017, 2006 vs. 1996 GLs.

of the chemical industry, whereas in previous inventories they are included in the mineral industry worksheet and applied to the overall emissions from the mineral industry. In terms of metal production in 2017, the value is zero because the Pakistan's Steel industry was shut down in 2017 and has not yet been operational. This is why the metal production emission growth rate dropped to −100% due to zero value in the year 2017.

4. Comparative analysis of GHG inventories using 2006 and 1996 GLs

4.1. Source categorization and global warming potential

It is evident that under 2006 GLs, energy and waste remain separate sectors. However, industrial processes, and solvent and other product use are integrated as one sector −IPPU. To deal with emissions from the non-energy use of fuels, 2006 GLs clearly establishes the boundary between the energy sector and IPPU compared to 1996 GLs, and such emissions are now reported mainly in the IPPU sector. The 2006 GLs introduces a broader concept of 'excluded carbon' for the non-energy use of fuels which includes not only 'stored carbon' (old term in 1996 GLs) but also carbon used and emitted as CO_2 in other sectors quite often within the IPPU (not just in the energy sector). The 2006 GLs also merge agriculture, and land use change and forestry as the agriculture, forestry and other land use (AFOLU) sector to facilitate effective use of information. The source categorization also varies on a more disaggregated level between the two versions of IPCC GLs.

Another major distinction between the 2006 GLs and the 1996 GLs is the defined global warming potential (GWP) values. Decision 17/CP.8 under the convention states that the GWP values provided by the IPCC Second Assessment Report (IPCC, 1996) based on the effects of GHGs over a 100-year time horizon should be used by non-Annex I Parties (UNFCCC, 2003b). However, the Annex-I countries from 2015 onwards will use the GWP values provided by the IPCC Fourth Assessment Report (IPCC, 2007) as agreed by Decision 24/CP.19 (UNFCCC, 2014). Further, the latest Decision 18/CMA.1 (UNFCCC, 2019b) specifies that each party shall use the GWP values from the IPCC Fifth Assessment Report (IPCC, 2013). The GWP values used in reporting aggregated emissions based on 1996 GLs were taken from IPCC in its Second Assessment Report. Therefore, the same GWP values

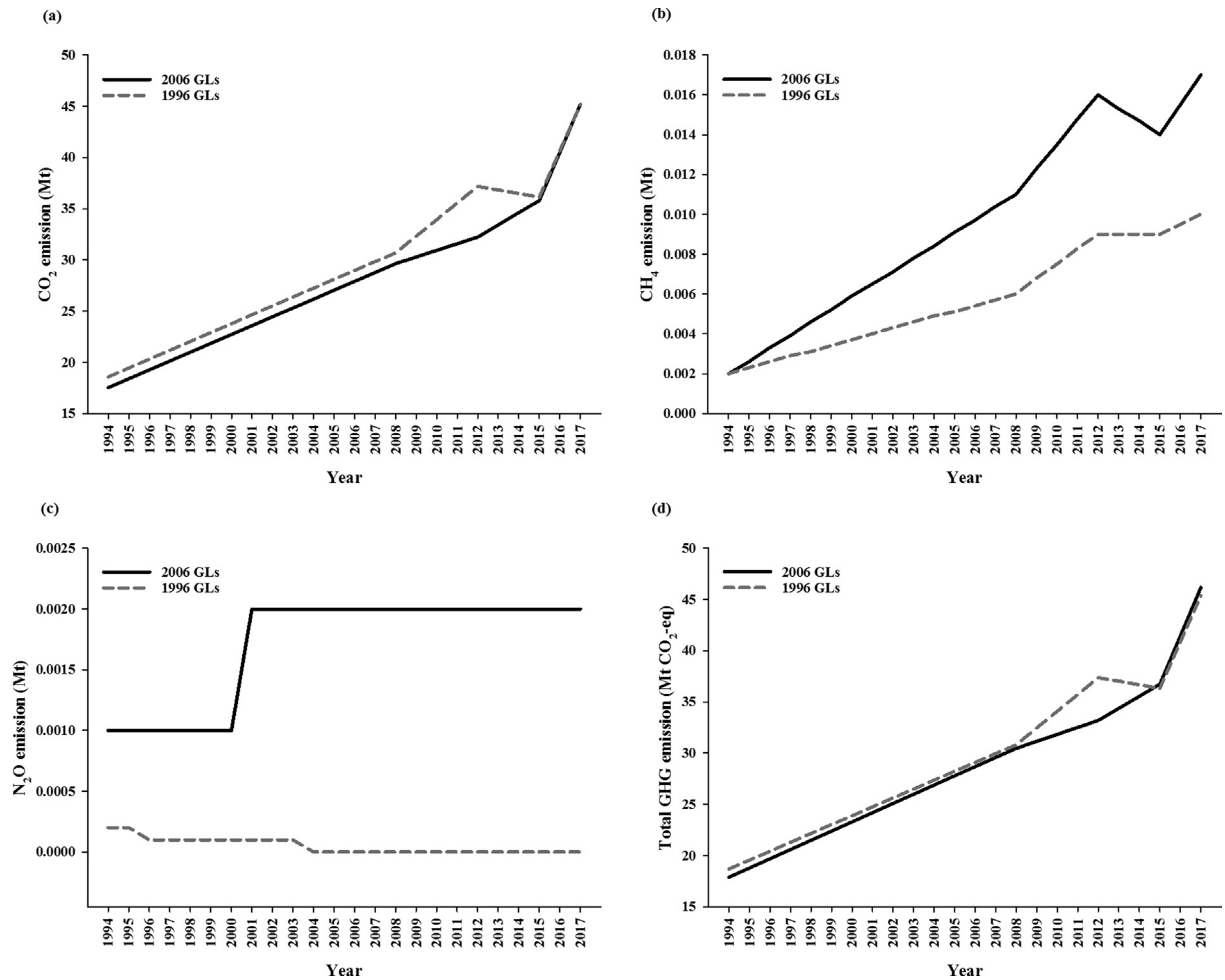

Fig. 6. Difference in GHG emissions in the transport sector in Pakistan during 1994−2017, 2006 vs. 1996 GLs.

are also used in reporting aggregated emissions based on 2006 GLs to keep the consistency.

4.2. Comparison by sector

4.2.1. Energy sector overall difference

Fig. 3 shows the overall gap in the time series of 2006 and 1996 GLs estimates. Although the gap is noticeable for CH_4 and N_2O, the total CO_2-eq emissions according to the 2006 GLs replicate those based on the 1996 GLs because the CO_2 emissions are dominant and demonstrate similar emission quantities over the period of interest. The significant difference in CH_4 emission quantities is due to the large inconsistency present in the CH_4 emission factors between two GLs for estimating fugitive emissions from oil (production, transport, and refining) and natural gas (processing, and distribution) operations.

4.2.2. Energy sector sub-sectoral differences

4.2.2.1. Energy industries. Fig. 4 shows the difference between the emission (CO_2, CH_4, N_2O, and the total) estimates from the 2006 and 1996 GLs in the energy industries. These industries primarily cover fuel consumption for electricity generation, gas processing plants, and petroleum refining. The total amounts of the total estimated by both GLs overlay each other and show quantities that are almost similar. The trends in the estimates of CO_2 emissions are also similar to those of CO_2-eq. However, the CH_4 emissions remained uniform until 2015, after which they doubled (0.001 Mt to 0.002 Mt) in 2017 (with the 2006 GLs) because Pakistan did not include the fuel consumption for petroleum refinery in the inventories based on the 1996 GLs. Petroleum refining was also considered for the other years (1994, 2008, 2012, 2015) based on the estimates using the 2006 GLs, but the CH_4 emissions overlapped with the estimates using the 1996 GLs because of the low consumption level. The trend in N_2O emissions in 2008−2017 (based on already available 1996 GLs estimates) overlays the origin line as the value reported in the 2008, 2012, 2015 and 2017 summary tables is zero. This is simply because the UNFCCC software rounds off decimals when generating the summary tables. It means that the value is not necessarily zero, but very close to zero. The same trend can also be seen in the manufacturing and transport sectors; however, the reason for this is the same as before. In 1994, the fuel consumption for petroleum refining was very small, the reason for the 1994 N_2O

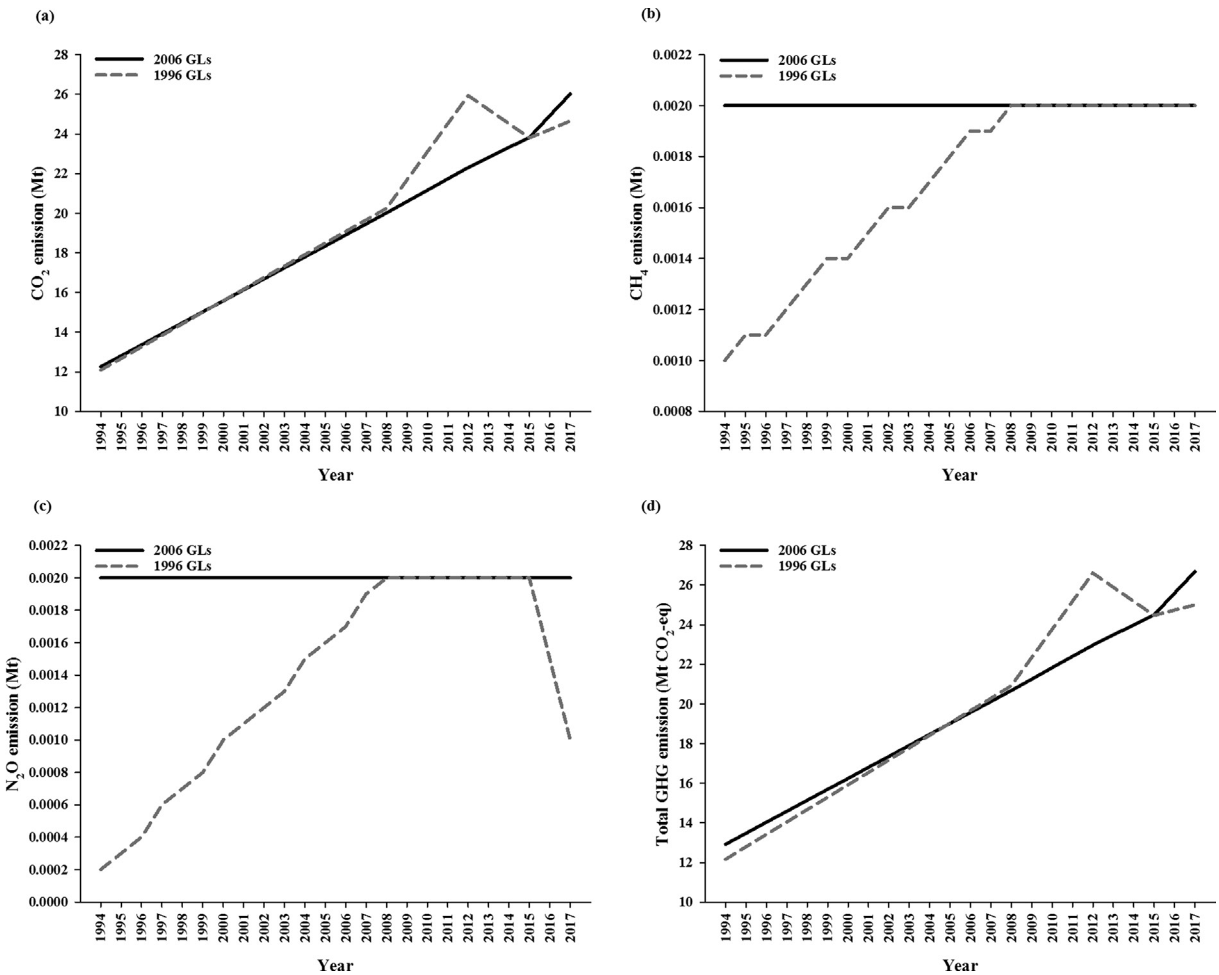

Fig. 7. Difference in GHG emissions in other sectors (residential, commercial, and agriculture) of energy sector in Pakistan during 1994–2017, 2006 vs. 1996 GLs.

emission value being the same for the estimates using both GLs. In summary, it is appropriate to mention here that the emission factors of the energy industries were the same for both GLs, and that the marginal difference arose because of the inclusion of additional source category in the energy industries.

4.2.2.2. Manufacturing industries. Fig. 5 shows the emissions gap in the energy sector for the manufacturing industries. The manufacturing industries include the fuel used in Pakistan steel mills, the cement industry, the fertilizer industry, and other general industries. Production of steel and cement in Pakistan is believed to use coking coal and other bituminous coal, imported mostly from other countries. The default emission factor in both GLs is the same for coking coal and other bituminous coal. However, it is assumed that Pakistan's brick kiln industry uses sub-bituminous coal, which has a higher emission factor compared with coking coal and other bituminous coal. For the estimates of both GLs, the difference between CO_2 and CO_2-eq is not significant. However, the difference is visible for both CH_4 and N_2O. The CH_4 emissions by 1996 GLs were higher than the 2006 GLs because of higher CH_4 emission factors for oil, gas, and coal defined in 1996 GLs. The N_2O emissions obtained with the 2006 GLs are more than those estimated with the 1996 GLs because of the higher emission factor for coal (other bituminous and sub-bituminous) in the 2006 GLs. There is no difference in the fuel consumption data that were used to calculate emissions following both GLs.

4.2.2.3. Transport sector. Fig. 6 shows the difference in GHG emissions between the 2006 and 1996 GLs in the transport sector. The trends for CO_2-eq and CO_2 overlay, with the exception of the year 2012, in which the estimates with the 1996 GLs are higher than those with the 2006 GLs. The reason for the different estimate for the year 2012 is that the value for diesel consumption used in the 1996 GL based inventory for 2012 for the mobile agricultural/forestry/fishing sector was taken from a reference energy scenario generated by the Pakistan Integrated Energy Model (Pak-IEM, 2010). This value was projected on the basis of the model rather than being the actual value based on national statistics, which, however, is lower than the projected value. This discrepancy would explain the difference in total emissions for 2012. The difference between CH_4 and N_2O emissions is attributable to the fact that the 2006 GLs provide updated fuel-specific gasoline, diesel, and natural gas emission factors that are higher than those estimated using the 1996 GLs. That is why the 2006 GLs

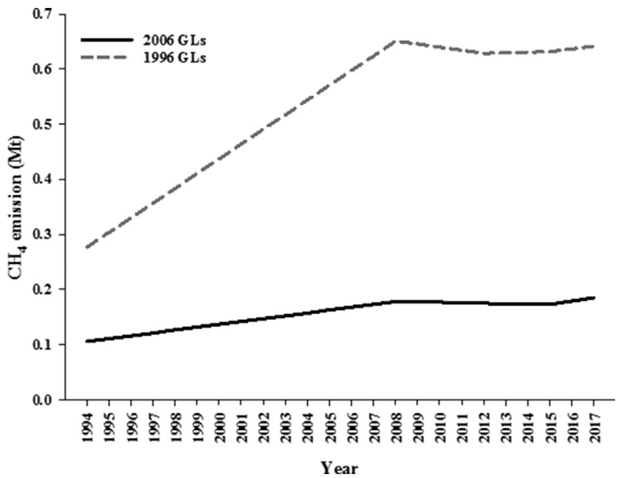

Fig. 8. Difference in fugitive GHG emissions in Pakistan during 1994−2017, 2006 vs. 1996 GLs.

based emission quantities of CH_4 and N_2O from transport sector are higher compared to 1996 GLs.

4.2.2.4. Other sectors. Fig. 7 shows the emission gap for other sectors including residential, commercial/institutional, and agriculture/forestry/fishing between the 2006 and 1996 GLs. The trend for all GHGs and CO_2 emissions are quite similar except for the year 2012 in which the estimates for the 1996 GLs are higher than the estimates for 2006 GLs. The reason for this is the use of the scenario value modeled by Pakistan Integrated Energy Model (Pak-IEM, 2010) for diesel consumption in agricultural transport in 2012. This modeled diesel value is higher than the actual value based on national statistics, with the result being the gap in total emissions for 2012. Nevertheless, the CH_4 and N_2O emissions estimated according to the 2006 GLs exhibit flat patterns, despite some variations in the estimates based on the 1996 GLs (Fig. 7b and c). The reason for the difference is that the value of the 1994 emission inventory for these two GHGs was not available; therefore, the values are based on expert judgment. Furthermore, the default CH_4 and N_2O emission factors in the category of agriculture/forestry/fishing (for mobile combustion only) were updated in 2006 GLs (CH_4 4.15 kg $(TJ)^{-1}$; N_2O 28.6 kg $(TJ)^{-1}$ compared to the 1996 GLs (CH_4 5 kg $(TJ)^{-1}$; N_2O 0.6 kg $(TJ)^{-1}$).

4.2.2.5. Fugitive emissions. Fig. 8 shows the fugitive CH_4 emissions and the considerable difference between the

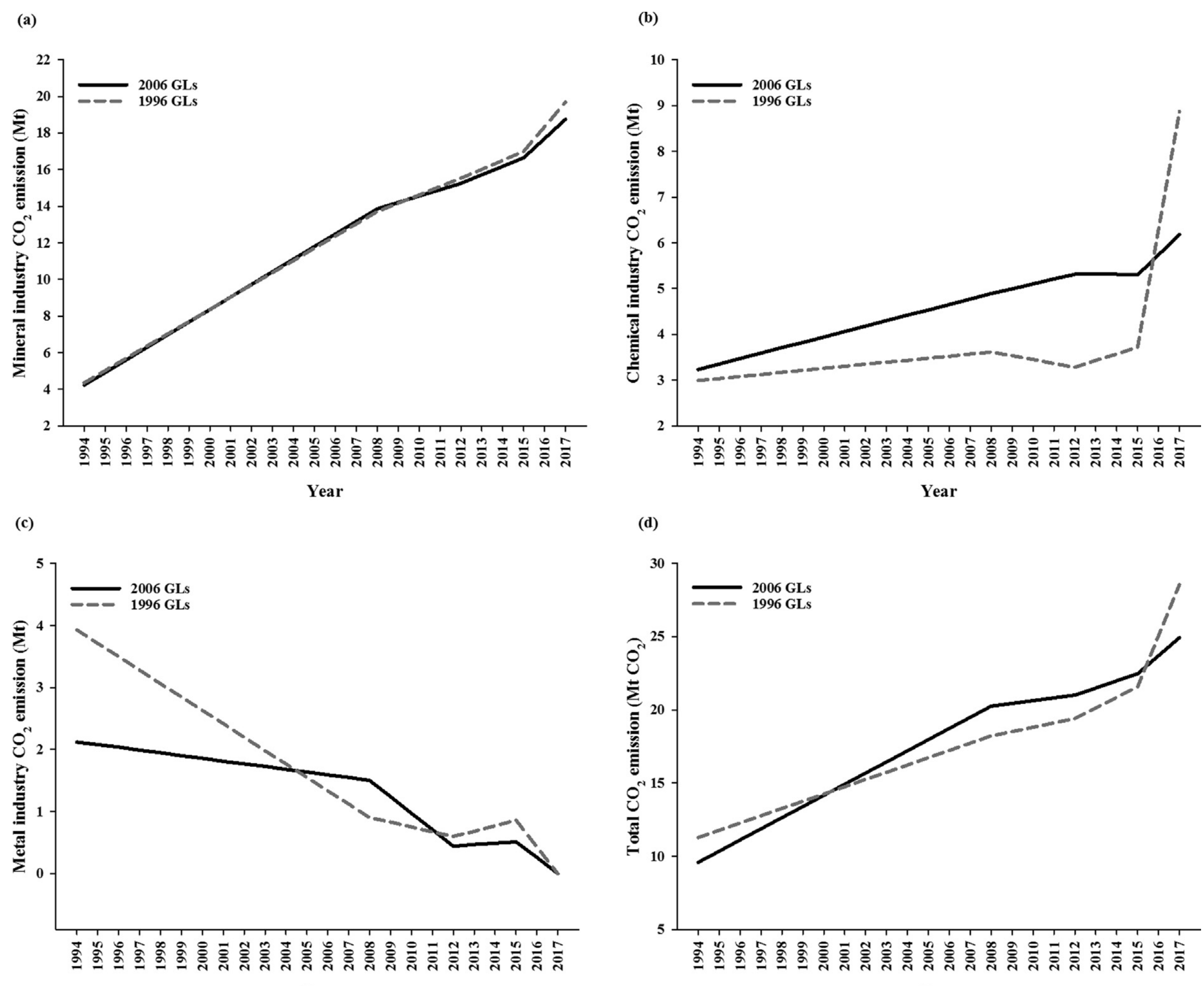

Fig. 9. IPPU sector overall gap of CO_2 emissions in Pakistan during 1994−2017, 2006 vs. 1996 GLs.

estimates based on the 2006 GLs and 1996 GLs. This difference can be attributed to the application of very high emission factors taken from the 1996 GLs for natural gas production and distribution. In the 2006 GLs, the emission factors were revised and have a reduced range compared to the 1996 GLs. This clarifies why the estimates with the 2006 GLs have lower emission values than those with the 1996 GLs.

4.2.3. IPPU sector overall and sub-sectoral differences

Fig. 9 shows the difference between the 2006 GLs and 1996 GLs for GHG emissions of the IPPU sector. The difference is negligible for the mineral industry, which is mostly concerned with cement production. The data on cement production was taken from Pakistan Economic Surveys and all cement production is presumed to be mainly that associate with Portland cement in Pakistan. According to the 2006 GLs, a default value of 95% is used to indicate the clinker fraction in cement. However, a difference exists for the chemical industry because of the use of different methodologies of both GLs. The estimates of the 1996 GLs use the urea production to calculate the amount of CO_2, whereas the 2006 GLs use the amount of ammonia that was produced. Similarly, soda ash emissions are reported in the chemical industry, according to the 2006 GLs, whereas in previous inventories the emissions were considered under the mineral industry. In terms of the metal industry (iron and steel production), the CO_2 emissions were estimated as zero in 2017. This is because the Pakistan steel industry was shut down in 2017, resulting in no coke or pig iron production according to national statistics. The trend for the metal industry also shows that iron and steel production in Pakistan has continued to decline since 1994.

5. Conclusions

The study found that the 2006 GLs based total CO_2 equivalent emissions from the energy and IPPU sectors show a relative difference of 4% and −1% compared to those based on 1996 GLs, respectively. In the energy sector, with an average annual growth rate of 3.6%, CO_2 is the most abundant GHG released into the atmosphere followed by CH_4 and N_2O. Although the gap in energy sector emissions is notable for CH_4 and N_2O, the overall CO_2 equivalent emissions based on the 2006 GLs replicate those reported by using the 1996 GLs. This is because the CO_2 emissions that are dominant, show similar amounts over the time series. Further, the fugitive emissions under energy sector represent significant gap between the two Guidelines. For the IPPU sector, the gap is relatively large in the chemical industry, but the difference in total GHG emissions is marginal between both GLs. However, the 2006 GLs endeavor to upgrade the accuracy and reliability of GHG inventories as a result of incorporating new sources and revised emission factors. For that reason, the GHG inventories by 2006 GLs is quite different from that by 1996 GLs. It is therefore recommended that Pakistan implement the 2006 GLs to improve the GHG inventories, as this has rarely been adopted by developing countries. This would also help to better identify the national targets for GHG reduction with respect to NDCs.

The results of the study are limited to Tier 1 method (using default emission factors) of IPCC GLs due to the unavailability of country-specific emission factor data. Although decision tree in 2006 GLs for estimating GHG emissions clearly recommends using higher tiers for key categories (key category analysis will be described in a subsequent publication (submitted)), most developing countries suffer from a lack of resources and experts, forcing to adopt Tier 1 method. In the long run, Pakistan should devote to develop Tiers 2 and 3 method reflecting country- and plant-specific emission characteristics. For the time being, Tier 1 method has been applied broadly despite of high uncertainty. In general, the uncertainties in the activity data are smaller as it is compiled and frequently reported by national statistical agencies, which may have already identified the uncertainties associated with data as part of their data collection procedures.

It should be noted that Pakistan has a well-managed system to compile and publish the national energy statistics annually. However, it must be made more dynamic by collecting the data in a format consistent with the GHG inventories requirement. This will further improve the data consistency and reduce data conversion errors, such as unit conversion. Information on the country-specific fuel properties such as carbon content, carbon oxidation factor, and fuel energy content − NCV is recommended to be reported in national energy statistics publication. Further, efforts should be made for road transport (a key category) to collect distance travelled data of vehicles by type and fuel to reflect true vehicle emissions under a higher Tier approach. The cement industry and the ammonia production has appeared to be the key categories in the IPPU sector. It is therefore recommended that the data concerning clinker production or the use of carbonate be made available and reported as part of national industry statistics for the cement industry. For the ammonia industry, instead of estimating emissions based on the ammonia production data, efforts should be made to get details on the total fuel demand for ammonia production. It would undoubtedly benefit Pakistan to achieve more reliable and accurate estimates of GHG emissions from energy and IPPU sector under a higher Tier.

Declaration of Competing Interest

The authors declare no conflict of competing interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.accre.2020.05.002.

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