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Comparative analysis of greenhouse gas emission inventory for Pakistan: Part II agriculture, forestry and other land use and waste

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Abstract

Understanding Pakistan's greenhouse gas (GHG) emission status is critical for identifying the national targets for GHG mitigation with respect to the nationally determined contributions (NDCs). This study focuses on the development of Pakistan's GHG (CO_2, CH_4, and N_2O) inventories for agriculture, forestry and other land use (AFOLU) and waste sectors using 2006 IPCC Guidelines. This study should be seen as a direct continuation of the preceding one (Part I [Available online at: https://doi.org/10.1016/j.accre.2020.05.002]) which discusses energy and industrial processes and product use in compliance with the 2006 and 1996 IPCC Guidelines. It also provides sector-specific comparative time series (1994−2017) analysis of GHG inventories, identification of key categories, and national GHG emissions trend for Pakistan. The results indicate an average relative difference (on average for time series 1994−2017) of 19% and 6% in total GHG emissions (CO_2-eq) from AFOLU and waste sector respectively between 2006 and 1996 IPCC Guidelines. The absolute difference over the entire time series for AFOLU and waste sector was in the range of 3−67 Mt CO_2-eq and 1−7 Mt CO_2-eq respectively. Findings further reveal that the quantity of national GHG emissions by 2006 IPCC Guidelines is 10% lower on average for complete time series compared to 1996 IPCC Guidelines. The average relative difference for total national emissions of CO_2, CH_4 and N_2O is −1%, 9%, and 48% respectively. Key category analysis based on 2006 IPCC Guidelines estimates identified three categories, each contributing ≥10% to the level assessment in the latest year 2017 and accounting for approximately half of the national GHG emissions. In order to further improve the reliability of GHG inventories, Pakistan needs to move from 1996 to 2006 IPCC Guidelines under a higher Tier approach particularly for identified key categories.

Keywords: Greenhouse gas; Emission inventory; Agriculture; Forestry and other land use; Waste sector; Time series analysis; Key categories; Pakistan

1. Introduction

The enhanced transparency framework (ETF) under the Paris Agreement (UNFCCC, 2015) requires each party (both Annex-I and non-Annex-I) to regularly provide a reliable national inventory of greenhouse gas (GHG) emissions (hereinafter referred to as GHG inventories) to the United Nations Framework Convention on Climate Change (UNFCCC) (UN, 1992). The ultimate objective is to track the individual progress of the parties in achieving their nationally determined contributions (NDCs) and joint progress towards the long-term objectives of the agreement. Further, the agreement stipulates to use good practice methodologies accepted by the Intergovernmental Panel on Climate Change (IPCC) for preparing transparent, accurate, consistent, comparable, and complete GHG inventories (UNFCCC, 2014a; Bergamaschi et al., 2018). In this regard, the latest updated

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guidance provided by the IPCC is the 2006 IPCC Guidelines for National GHG Inventories (hereinafter referred to as 2006 GLs) (IPCC, 2006), evolved from the previous Revised 1996 IPCC Guidelines for National GHG Inventories (hereinafter referred to as 1996 GLs) (IPCC, 1997). In terms of reporting under existing measurement, reporting, and verification (MRV) arrangements, non-Annex-I parties are required to submit GHG inventories in their national communications (NCs) and biennial update reports (BURs), and not annually as a stand-alone report like Annex-I parties (Zhu and Wang, 2013; UNFCCC, 2014b; Goodwin and Kizzier, 2018; Weikmans et al., 2020). However, under the ETF (Katowice outcome) all parties are required to submit their GHG inventories (to be based on 2006 GLs) as part of their first biennial transparency report (BTR1) or as a stand-alone report in accordance with the modalities, procedures and guidelines (MPGs) by 31 December 2024 at the latest. The follow-up work related to the development of common reporting tables, common tabular formats, and outlines of BTR under adopted MPGs is still underway (UNFCCC, 2019b).

Pakistan has reported GHG inventories (based on 1996 GLs) for years 1994 (UNFCCC, 2003a) and 2015 (GCISC, 2017) in its initial national communication (UNFCCC, 2003a) and second national communication (UNFCCC, 2019a) respectively. Pakistan also used the GHG inventory of 2015 (GCISC, 2017) in the NDCs to define baseline scenario target that ambitions to reduce emissions by 20% (all conditional) below projected emissions in 2030 (UNFCCC, 2016). In addition, ASAD (2016), GCISC (2016), and Mir et al. (2017) developed GHG inventories for the years 2008 and 2012 following 1996 GLs, with the exception of ASAD (2009) which is based on 2006 GLs and mentioned in MoPDR (2010) and MoCC (2012). Previously, UNFCCC Decision 24/CP.19 (UNFCCC, 2014a) and Decision 17/CP.8 (UNFCCC, 2003b) clarifies the differentiation of applying 2006 or 1996 GLs between Annex-I and non-Annex-I parties (Yona et al., 2020). However, Katowice outcome − Decision 18/CMA.1 (UNFCCC, 2019b) requires each party to apply 2006 GLs (in terms of updated methods, data, and certain parameters) to complete GHG inventories. Therefore, to improve the reliability and facilitate ETF in the Paris Agreement, Pakistan should use 2006 GLs for GHG inventories in meeting the reporting requirements. Noted that transitioning from 1996 GLs to 2006 GLs will result in an inventory reflecting quite different national GHG totals. This would indeed pose challenges whether a party has already planned for NDCs implementation using previous estimates based on 1996 GLs (Goodwin and Kizzier, 2018).

This study explores the quantitative implications (sectoral as well as total) of applying 2006 GLs compared to 1996 GLs in Pakistan's GHG inventories. The aim of this study is to: i) develop new 2006 GLs based GHG inventories; ii) build a consistent time series (1994−2017) of annual estimates; and iii) conduct key category analysis (KCA) for Pakistan. The research outcomes will help policy makers prioritize the key GHGs and categories to be targeted in Pakistan's NDCs. In the series of two studies, Part I (Mir et al., 2020) has previously studied the energy and industrial processes and product use. Nevertheless, Part II covers the agriculture, forestry, and other land use (AFOLU) and waste sectors along with the KCA and national GHG emissions trend.

2. Methods and data

For AFOLU and waste sectors, most of the data sources − UNFCCC (2003a), MoF (2008, 2012, 2015, 2017), ASAD (2009, 2016), FAO (2015), GCISC (2016, 2017), Mir et al. (2017), MoNFSR (2019) and general methodology for estimating emissions and missing years inventory data − IPCC (1997, 2006) was similar to those already cited in Part I except following additional data sources − FAO (2009, 2010, 2019), MoF (2009, 2011, 2014), Zaman and Ahmad (2012), Masood et al. (2014), Kawai and Tasaki (2016), Kaza et al. (2018), and Ilmas et al. (2019).

Moreover, this study includes the key category analysis (KCA) that was carried out in accordance with the 2006 GLs. The KCA covering three GHGs (CO_2, CH_4, N_2O) was conducted for the years 1994 (as the base year) and 2017 (as the latest year). To identify the most important GHG emission sources for sectoral estimates of both GLs, the IPCC Approach 1 (level and trend assessment) with a suggested 95% threshold was used (IPCC, 2006). Similarly, the IPCC suggested aggregation level of analysis for Approach 1 was applied for source categories to determine the key categories (KCs). The description of methodological approach and formula used to identify KCs is provided in Section 4.3.1 of the 2006 GLs (IPCC, 2006). It is important to remember here that 1996 GLs do not include guidance on KCA, but the IPCC Good Practice Guidance (IPCC, 2000) is recommended to be used by inventory experts to perform KCA.

The KCs (for both GLs estimates) were then arranged by combining all categories identified by the level assessment (for 1994 and 2017) and by the trend assessment (from 1994 to 2017). It was achieved by summarizing all KCs by sector and specifically defining the identification criterion, i.e. whether the category was identified either by level or trend assessment, or by both level and trend assessment, either in the 1996 GLs or 2006 GLs estimates, or in the both GLs estimates.

3. Key category analysis

KCA was conducted to identify significant GHG emission sources in Pakistan GHG inventory in terms of absolute emission levels and trends. It will enable better resource allocation on established KCs in a cost-effective manner to reduce the uncertainty in GHG inventories. Key categories were identified for base year 1994 and the latest year 2017 for all the three GHGs considered in this study. To perform KCA, a total of fifty-six source categories were used to disaggregate the total GHG emissions in Pakistan. The category disaggregation level was selected based on the 2006 GLs recommendation (IPCC, 2006). An overall consolidated summary of KCA for Pakistan using Approach 1 (level and trend) for 1996 and 2006 GLs based estimates is summarized in Table 1.

Using 2006 GLs based estimates for the latest year 2017, Approach 1 level assessment identified fifteen KCs (Table A1) out of total fifty-six source categories. Among the 15 KCs, the energy sector shared the largest CO_2-eq emissions in 2017 and responsible for eight KCs. The other KCs consist of two categories from IPPU sector, four categories from AFOLU sector, and one category from the waste sector. There were three main categories which represented ≥10% contribution in the level assessment, two from the energy sector (fuel combustion, transport, road transportation, liquid and gaseous fuels, CO_2 (12%), and fuel combustion, energy industries, gaseous fuels, CO_2 (10%)) and one from the AFOLU sector (enteric fermentation, CH_4 (25%)). Among the top ten in KCs by level assessment, enteric fermentation, direct N_2O emissions from managed soils, cement production from the mineral industry, and forest land remaining forest land were not related to the energy sector as shown in Table A1. Table A1 also provides the KCA of latest year 2017 estimates based on 1996 GLs.

In case of the base year 1994, the level assessment defined seventeen KCs (Table A2). The KCs consists of eight categories from the energy sector, three categories from the IPPU sector, five categories from the AFOLU sector, and one category from the waste sector. Among the top ten in KCs by level assessment, enteric fermentation, direct N_2O emissions from managed soils, and forest land remaining forest land were not related to the energy sector as presented in Table A2. Table A2 also provides the KCA for estimates of the base year 1994 based on 1996 GLs.

In comparison for 2006 GLs based estimates, the categories which were key categories in base year 1994 but no longer in latest year 2017 were rice cultivation (CH_4) and Metal industry − iron and steel production (CO_2). However, all the key categories in the latest year 2017 were also identified in base year 1994. Similarly, in comparison for 1996 GLs based estimates, the categories which were key categories in base year 1994 but no longer in latest year 2017 were rice cultivation (CH_4) and Metal industry − iron and steel production (CO_2). However, the category which was key category in the latest year 2017 but not in the base year 1994 was solid waste disposal (CH_4).

Table 1
Summary of key category analysis for Pakistan, 2006 and 1996 GLs (Level and trend assessment approach 1, 1994 (base year) and 2017 (latest year)).

Sector	IPCC category code	IPCC category	GHG	Identification criteria	Comments
Energy	1.A.3.b	Fuel combustion activities − Transport − Road transportation − Liquid + Gaseous fuels	CO_2	L1, T1	Identified by Level & Trend in both GLs
	1.A.2	Fuel combustion activities − Manufacturing industries and construction − Solid fuels	CO_2	L1, T1	Identified by Level & Trend in both GLs
	1.A.1	Fuel combustion activities − Energy industries − liquid Fuels	CO_2	L1, T1	Identified by Level & Trend in both GLs
	1.A.1	Fuel combustion activities − Energy industries − gaseous Fuels	CO_2	L1, T1	Identified by Level & Trend in both GLs
	1.A.2	Fuel combustion activities − Manufacturing industries and construction − Gaseous fuels	CO_2	L1, T1	Identified by Level & Trend in both GLs
	1.A.4	Fuel combustion activities − Other sectors − Liquid fuels	CO_2	L1, T1	Identified by Level & Trend in both GLs
	1.A.2	Fuel combustion activities − Manufacturing industries and construction − Liquid fuels	CO_2	L1, T1	Identified by Level & Trend in both GLs
	1.A.4	Fuel combustion activities − Other sectors − Gaseous fuels	CO_2	L1, T1	Identified by Level & Trend in both GLs
	1.A.3.a	Fuel combustion activities − Transport − Civil aviation (domestic) − Liquid fuels	CO_2	T1	Only identified by Trend in both GLs
	1.B.1	Fugitive emissions from fuels − Solid fuels	CH_4	T1	Only identified by Trend in both GLs
	1.B.2.b	Fugitive emissions from fuels − Oil and natural gas − Natural gas	CH_4	T1	Only identified by Trend in both GLs
	1.B.2.a	Fugitive emissions from fuels − Oil and natural gas − Oil	CH_4	T1	Only identified by Trend in 1996 GLs
Industrial processes and product use	2.A.1	Mineral industry − Cement production	CO_2	L1, T1	Identified by Level & Trend in both GLs
	2.B.1	Chemical industry − Ammonia production	CO_2	L1, T1	Identified by Level & Trend in both GLs
	2.C.1	Metal industry − Iron and steel production	CO_2	T1	Only identified by Trend in both GLs
Agriculture, forestry and other land use	3.A.1	Enteric fermentation	CH_4	L1, T1	Identified by Level & Trend in both GLs
	3.C.4	Direct N_2O emissions from managed soils	N_2O	L1, T1	Identified by Level & Trend in both GLs
	3.B.1.a	Forest land remaining forest land	CO_2	L1, T1	Identified by Level & Trend in both GLs
	3.A.2	Manure management	CH_4	L1, T1	Identified by Level & Trend in both GLs
	3.C.7	Rice cultivations	CH_4	T1	Only identified by Trend in 1996 GLs
Waste	4.A	Solid waste disposal sites − Municipal solid waste	CH_4	L1, T1	Identified by Level & Trend in both GLs
	4.D	Wastewater treatment and discharge (domestic + industrial)	CH_4	T1	Only identified by Trend in 2006 GLs
	4.D	Wastewater treatment and discharge (domestic)	N_2O	T1	Only Identified by Trend in both GLs

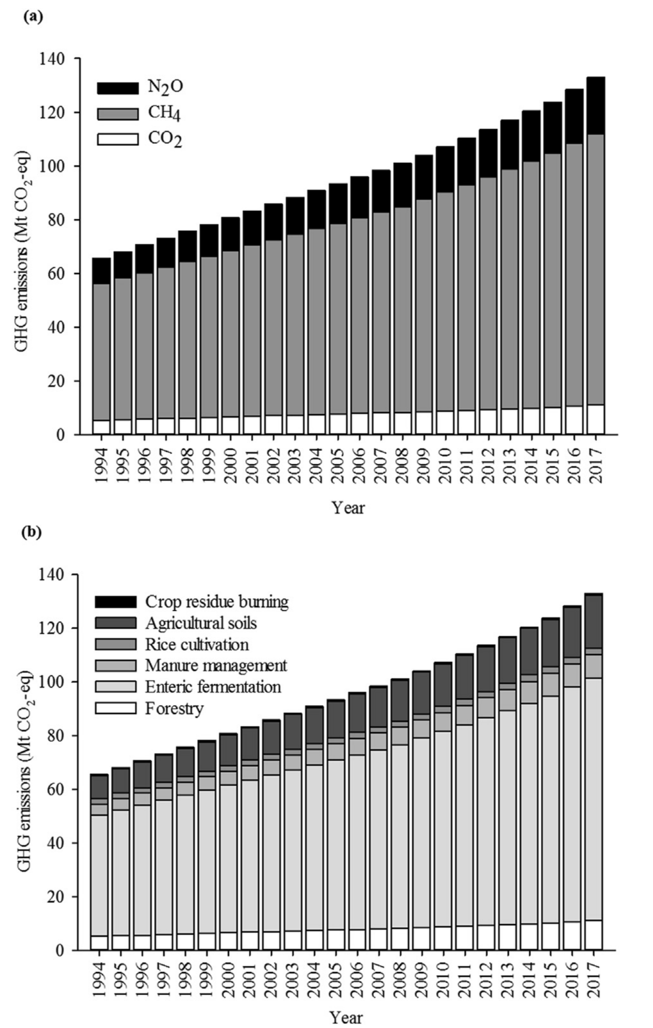

Fig. 1. GHG emissions from the AFOLU sector of Pakistan using 2006 GLs during 1994−2017 (a) by gas and (b) by sub-sector.

With regard to trend assessment between the base year 1994 and latest year 2017 for 2006 GLs based estimates, Approach 1 identified twenty-two categories as trend KCs. The KCs consists of eleven categories from energy sector, three categories from IPPU sector, five categories from AFOLU sector, and three categories from the waste sector. Among the top ten in KCs by trend assessment, enteric fermentation, direct N_2O emissions from managed soils, and forest land remaining forest land were not related to the energy sector as shown in Table A3. Table A3 also provides the KCA by trend assessment for 1996 GLs based estimates between the base year 1994 and latest year 2017.

Table 1 shows an overall consolidated summary of KCA for Pakistan taking into account both the 2006 and 1996 GLs based estimates. Of the twenty-three KCs in total, fifteen were identified by both level and trend assessment in both GLs estimates. There are five KCs that were only identified by trend assessment in both GLs estimates. However, only by trend assessment, in 1996 GLs estimates two categories were identified as key categories, and one in 2006 GLs based estimates. Further, the overall share of GHGs in all the twenty-three KCs in Table 1 is CO_2 − 56%, CH_4 − 35%, and N_2O − 9%. This may suggest that, in terms of mitigation, the source categories emitting CO_2 and CH_4 (91% total share) should be prioritized.

4. Time series GHG inventories using 2006 GLs

4.1. Agriculture, forestry and other land use (AFOLU) sector

In Pakistan, the AFOLU sector accounted for 37% of total GHG emissions in 2017, corresponding to 132.96 Mt CO_2-eq (Fig. 1a). The AFOLU sector is the most important source of GHG emissions in Pakistan. GHG emissions from the agricultural sector in 2017 were estimated at 121.82 Mt CO_2-eq representing 34% of total GHG emissions in Pakistan, while the forestry sector was responsible for 3% of total GHG emissions in 2017 (Fig. 1b). Enteric fermentation and agricultural soils were the main sources of GHG emissions in the agricultural sector. CH_4 in the AFOLU sector was the most prevalent GHG with an annual average growth rate of 3%, followed by N_2O and CO_2. Over the entire period from 1994 to 2017, the GHG emissions from the AFOLU sector increased linearly possibly due to the consistent growth in livestock population and use of synthetic fertilizers in Pakistan. CO_2 emissions from the forestry sector are mainly attributed to the changes in forest and other woody stocks of biomass. Fig. 1 shows the trend in the AFOLU sector of Pakistan for individual GHGs and sub-sectoral CO_2-eq emissions.

The agriculture sector maintained the largest percentage contribution in the AFOLU sector compared with other source category (forestry sector), accounting for 92% (on average) of total AFOLU sector emissions. The agriculture sector includes mainly enteric fermentation (livestock), manure management (livestock), rice cultivation, agricultural soils, and crop residue burning (IPCC, 1997, 2006). Table 2 presents a comprehensive overview of the quantity of GHG emissions released from the categories of AFOLU sector. The enteric fermentation accounts for 68% of total GHG emissions from the AFOLU sector followed by the agricultural soils category (14%). The share of GHG emissions from the forestry and manure management was smaller than enteric fermentation and agricultural soils and represent the average of about 8% and 6% of the total GHG emissions from the AFOLU sector, respectively. The sub-sectors of the rice cultivation and crop residue burning shows considerably low shares of 2% and 0.5%, respectively.

It is observed that the annual average growth rate of about 3% for the GHG emission from enteric fermentation is relatively low compared with that from agricultural soils. The enteric fermentation category mainly includes CH_4 emissions from various livestock species such as cattle, buffalo, sheep, goats, camels, horses, mules and asses. On the other hand, GHG emissions from the agricultural soils showed the largest annual average growth rate of nearly 4%. This includes all managed soils on land including forest land which is managed. The manure management and forestry sector were

Table 2
GHG emissions from the AFOLU sector of Pakistan for 1994−2017 (2006 GLs; unit: Mt CO_2-eq).

Year	Agriculture						Forestry and other land use (Total (B))[a]	Total[b] (A + B)
	Enteric fermentation	Manure management	Rice cultivation	Agricultural soils	Crop residue burning	Total (A)		
1994	45.07	4.19	1.95	8.68	0.40	60.29	5.26	65.54
1995	46.73	4.36	1.97	9.15	0.41	62.61	5.47	68.08
1996	48.40	4.53	1.99	9.61	0.41	64.93	5.68	70.61
1997	50.06	4.69	2.01	10.08	0.41	67.25	5.89	73.14
1998	51.73	4.86	2.03	10.54	0.41	69.57	6.10	75.67
1999	53.39	5.03	2.05	11.01	0.42	71.89	6.31	78.21
2000	55.06	5.20	2.07	11.47	0.42	74.21	6.53	80.74
2001	56.72	5.36	2.10	11.94	0.42	76.54	6.74	83.27
2002	58.39	5.53	2.12	12.40	0.42	78.86	6.95	85.80
2003	60.05	5.70	2.14	12.87	0.43	81.18	7.16	88.34
2004	61.72	5.87	2.16	13.33	0.43	83.50	7.37	90.87
2005	63.38	6.03	2.18	13.80	0.43	85.82	7.58	93.40
2006	65.05	6.20	2.20	14.26	0.43	88.14	7.79	95.94
2007	66.71	6.37	2.22	14.73	0.44	90.46	8.01	98.47
2008	68.38	6.54	2.24	15.19	0.44	92.78	8.22	101.00
2009	70.64	6.74	2.25	15.58	0.44	95.65	8.49	104.14
2010	72.90	6.95	2.27	15.97	0.44	98.52	8.76	107.28
2011	75.16	7.15	2.28	16.35	0.44	101.39	9.03	110.42
2012	77.43	7.36	2.29	16.74	0.44	104.25	9.31	113.56
2013	79.86	7.68	2.39	17.05	0.45	107.43	9.56	116.99
2014	82.30	8.01	2.48	17.36	0.46	110.61	9.82	120.43
2015	84.74	8.34	2.58	17.67	0.47	113.79	10.08	123.86
2016	87.47	8.60	2.50	18.76	0.48	117.80	10.61	128.41
2017	90.20	8.86	2.43	19.84	0.49	121.82	11.15	132.96
CAGR[c]	3.1%	3.3%	1.0%	3.7%	0.9%	3.1%	3.3%	3.1%

Notes:
[a] This includes ‘changes in forest and other woody biomass stock’.
[b] May not sum similar to total due to rounding.
[c] CAGR means compound annual growth rate, calculated by (latest value/base value)$^{(1/\text{no. of years})}$ − 1.

accompanied by the average annual growth rate of 3.3% separately. The overall annual average growth rate of agriculture sector was almost equal to that of GHG emissions from the forestry sector. In addition, all categories indicated a positive annual average growth rate over the entire period. The average annual growth rate for rice cultivation and crop residue burning was 1.0% and 0.9%, respectively (Table 2).

As the enteric fermentation holds the major share of the AFOLU sector's GHG emissions, a closer look was taken at its GHG emissions. Fig. 2 shows the comprehensive breakdown of GHG emitted from enteric fermentation during the period 1994 to 2017. The related data is also provided in Table A4. CH_4 emissions hold the largest amount and proportion of GHG emissions in this sub-sector. All GHG emissions from this sub-sector increased from 1994 to 2017. Due to the important contribution of buffalo livestock (49%), overall enteric fermentation emissions had an average annual growth rate of 3.1%.

4.2. Waste sector

In Pakistan, the waste sector accounted for 3% of total GHG emissions in 2017, equivalent to 9.3 Mt CO_2-eq (Fig. 3a). In terms of emission quantity, the waste sector was positioned at the fourth major source of GHG emissions followed by the energy, AFOLU, and IPPU sectors. The primary sources of GHG emissions in the waste sector were solid waste disposal sites (SWDS), and wastewater treatment and discharge (WWTD) (Fig. 3b). CH_4 was the most prevalent GHG in the waste sector with an annual average growth rate of 3.4% followed by N_2O (4.1%). The GHG emissions from the waste sector increased over the entire period from 1994 to 2017. Emissions of CH_4 from the waste sector are largely due to SWDS and WWTD. Fig. 3 presents GHG emissions from the waste sector of Pakistan using 2006 GLs during 1994−2017 by gas and by sub-sector.

Table A5 provides a detailed overview of the waste sector's GHG emissions. The annual average growth rate (3.5%) was seen to be the same for both SWDS and WWTD sub-sectors in the waste sector. Fig. 3 shows that SWDS were the major contributor to GHGs in the waste sector, accounting for 67% (on average) of total GHG emissions from the waste sector. The WWTD was the second largest GHG emitter, with a 33% overall contribution to waste sector GHG emissions. The First Order Decay (FOD) method (IPCC, 2006) was applied to estimate GHG emissions from SWDS following the 2006 GLs. This method is based on the assumption that the CH_4 generation capacity of waste disposed in a particular year will slowly decrease over the next decades. The FOD model is based on an exponential factor representing the fraction of degradable material that each year is degraded to CH_4 (IPCC, 2006). The model's key input is the amount of degradable

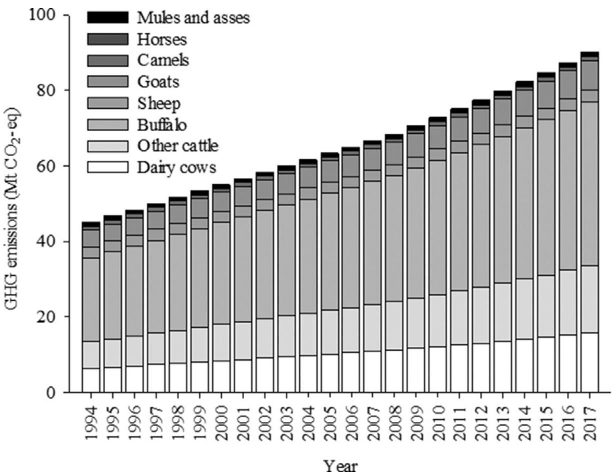

Fig. 2. GHG emissions from the enteric fermentation in Pakistan for 1994−2017 (2006 GLs).

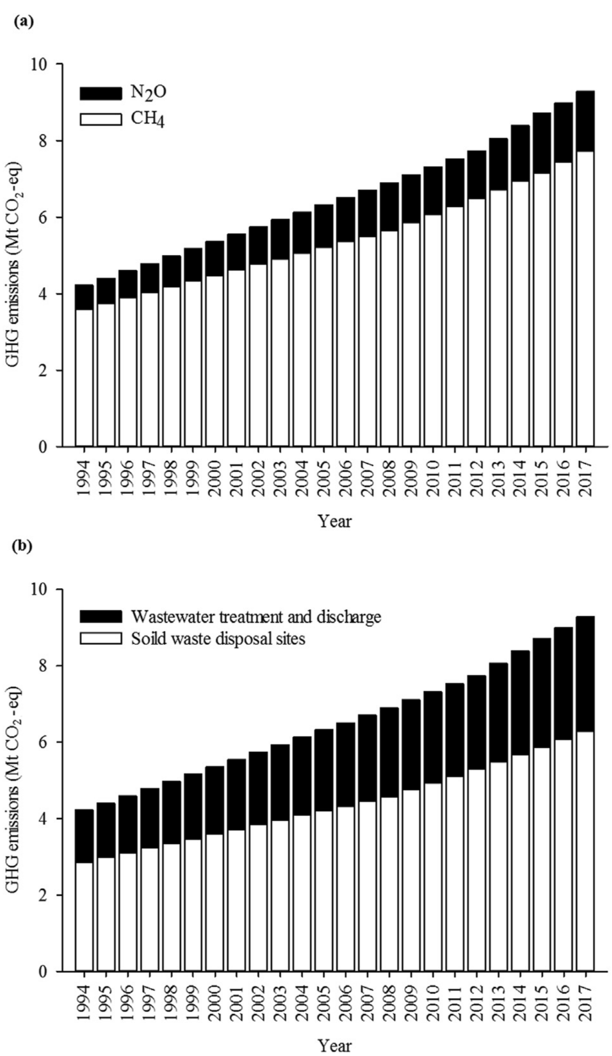

Fig. 3. GHG emissions from the waste sector of Pakistan using 2006 GLs during 1994−2017 (a) by gas and (b) by sub-sector.

organic carbon (DOC) disposed of in SWDS waste. This is estimated on the basis of information on disposal of various categories of waste (municipal solid waste, sludge, industrial and other waste) and the different types of waste (food, paper, wood, textiles, etc.) included in these categories, or alternatively as a mean DOC in disposed of bulk waste. In this analysis, the DOC in the disposal of bulk waste is used. Over 50 years from the first year of disposal at each site, the FOD method required solid waste disposal information (amounts and composition) to be obtained by default. Consequently, emissions from SWDS were calculated using the FOD method from the year 1950. The WWTD category covers two components: domestic WWTD and industrial WWTD. GHG emissions from this sub-sector includes CH_4 and N_2O. Both domestic and industrial WWTD emitted CH_4 while N_2O is released only from domestic WWTD. The WWTD emissions were mostly from domestic WWTD, which contributes an average of around 70% of the sub-sectoral emissions.

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

5.1. Comparison by country-level

With the estimates following 2006 GLs, the IPPU sector showed the highest annual average growth rate (4.2%) compared to energy (3.5%), waste (3.5%), and AFOLU (3.1%) sectors over the entire time series. In view of all sectors, the total annual average growth rate of national GHG emissions in Pakistan for the whole time series (1994−2017) was 3.4%. Conversely, with the estimates following 1996 GLs, the waste sector showed the highest annual average growth rate (6.2%) compared to AFOLU (4.8%), IPPU (4.1%), and energy (3.8%) sectors over the entire time series. The total annual average growth rate of national GHG emissions in Pakistan for the whole time series (1994−2017) was 4.3%. Further, the GHG emission quantities calculated using the 2006 GLs for energy and IPPU sectors were close to those calculated by following the 1996 GLs. A relative difference of 4% and −1% was appeared for both the energy and IPPU sectors respectively (Mir et al., 2020). However, the GHG emission quantities estimated using the 2006 GLs for AFOLU and waste sectors indicated significant difference compared to those estimated by following the 1996 GLs. An average relative difference (on average for time series 1994−2017) of 19% and 6% was seen for both sectors respectively. Total national GHG emissions by 2006 GLs from all source sectors were significantly lowered (average relative difference of 10%) compared to 1996 GLs based estimates as presented in Table 3.

Fig. 4 represents the gap in national GHG emission quantities between 2006 and 1996 GLs. In general, it is noted that the 2006 GLs indicated lower emission values compared to the 1996 GLs. Nevertheless, it is clear from Fig. 4 that the gap for

Table 3
Comparison of national GHG emissions of Pakistan by sector for 1994–2017 (2006 vs. 1996 GLs; unit: Mt CO_2-eq).[a]

Year	2006 GLs inventory					1996 GLs inventory					AD[b] (Total)	RD[c] (Total (%))
	Energy	IPPU	AFOLU	Waste	Total (A)	Energy	IPPU[d]	AFOLU[e]	Waste	Total (B)		
1994	85.5	9.6	65.4	4.2	164.7	83.3	11.3	68.2	4.0	166.8	2.1	1
1995	89.8	10.3	68.0	4.4	172.5	88.3	11.8	72.1	4.2	176.3	3.8	2
1996	94.1	11.1	70.5	4.6	180.3	93.3	12.3	75.9	4.3	185.8	5.5	3
1997	98.4	11.9	73.0	4.8	188.0	98.4	12.8	79.7	4.5	195.3	7.2	4
1998	102.7	12.6	75.6	5.0	195.8	103.4	13.3	83.5	4.6	204.8	8.9	4
1999	107.0	13.4	78.1	5.2	203.6	108.4	13.8	87.3	4.8	214.3	10.6	5
2000	111.3	14.2	80.6	5.4	211.4	113.5	14.3	91.1	4.9	223.7	12.3	6
2001	115.6	14.9	83.2	5.6	219.2	118.5	14.7	94.9	5.1	233.2	14.1	6
2002	119.9	15.7	85.7	5.7	227.0	123.5	15.2	98.7	5.3	242.7	15.8	6
2003	124.2	16.4	88.2	5.9	234.8	128.6	15.7	102.5	5.4	252.2	17.5	7
2004	128.5	17.2	90.8	6.1	242.5	133.6	16.2	106.3	5.6	261.7	19.2	7
2005	132.8	18.0	93.3	6.3	250.3	138.6	16.7	110.1	5.7	271.2	20.9	8
2006	137.1	18.7	95.8	6.5	258.1	143.7	17.2	113.9	5.9	280.7	22.6	8
2007	141.4	19.5	98.4	6.7	265.9	148.7	17.7	117.7	6.0	290.2	24.3	8
2008	145.7	20.3	100.9	6.9	273.7	153.7	18.2	121.5	6.2	299.7	26.0	9
2009	146.0	20.4	104.0	7.1	277.6	155.8	18.5	134.0	7.3	315.7	38.1	12
2010	146.3	20.6	107.2	7.3	281.4	158.0	18.8	146.6	8.4	331.7	50.3	15
2011	146.7	20.8	110.3	7.5	285.3	160.1	19.1	159.1	9.5	347.7	62.4	18
2012	147.0	21.0	113.4	7.7	289.2	162.2	19.4	171.6	10.6	363.7	74.6	21
2013	149.4	21.5	116.9	8.1	295.8	161.7	20.1	175.7	12.2	369.7	73.9	20
2014	151.9	22.0	120.3	8.4	302.5	161.2	20.9	179.8	13.9	375.8	73.2	19
2015	154.3	22.5	123.7	8.7	309.2	160.6	21.6	183.9	15.6	381.8	72.6	19
2016	171.8	23.7	128.3	9.0	332.8	178.2	25.1	192.0	15.7	411.0	78.2	19
2017	189.4	24.9	132.8	9.3	356.5	195.8	28.5	200.1	15.8	440.3	83.8	19
CAGR[f] (%)	3.5	4.2	3.1	3.5	3.4	3.8	4.1	4.8	6.2	4.3		

Notes:
[a] For the purpose of comparison, GWP values from IPCC SAR has been used to calculate CO_2-eq emissions for both guidelines.
[b] AD mean Absolute Difference.
[c] RD mean Relative Difference, calculated for each year by $[(B-A)/B] \times 100$.
[d] This represents only industrial Processes (IP) emission by 1996 GLs.
[e] This represents sum of agriculture and land use change and forestry (LUCF) emissions by 1996 GLs.
[f] CAGR mean Compound Annual Growth Rate, calculated by (Latest Value/Base Value) $^{(1/\text{no. of years})} - 1$.

CO_2-eq emissions between 1994 and 2008 is insignificant. This might be due to the application of linear statistical interpolation method between the two years to calculate missing intermediate years (1995–2007) emission data. However, the gap in emission quantities gradually became significant for the period 2008–2017. The value differences might originate from the change in default emission factors, updates methods and parameters in 2006 GLs as well as the availability of two additional years' inventory data for Pakistan between 2008 and 2017.

Fig. 5 illustrates the share by GHGs in the time series of national GHG emissions using 2006 and 1996 GLs. It is noted that CO_2 is the most influential GHG for Pakistan compared with CH_4 and N_2O. With 2006 GLs, the average share of CO_2 in the time series of national GHG emissions was 60% followed by CH_4 (33%) and N_2O (7%). However, with 1996 GLs, the average shares of CO_2, CH_4, and N_2O in national GHG emissions were 54%, 33%, and 13% respectively. The 2006 GLs gives a higher share for CO_2 than the 1996 GLs however, the CH_4 share remains same in both GLs but for N_2O it is lowered compared to 1996 GLs. Table A6 compares national GHG emissions by gas using both GLs. The CO_2 emissions estimated using the 2006 GLs were close to those obtained by following the 1996 GLs. A relative difference of −1% (on average for entire time series) was noted. However, CH_4 and N_2O emissions calculated using the 2006 GLs revealed significant differences compared to the 1996 GLs. A relative difference of 9% and 48% (on average for entire time series) was noticed for CH_4 and N_2O respectively. The results suggest that the 2006 GLs tend to enhance the overall accuracy of emission estimates relative to the 1996 GLs. The quantitative difference in emissions between two GLs is mainly associated with the updated methods and improved default values in 2006 GLs. However, an upgrade of the default emission factors would not impact the parties already using Tier 2 or Tier 3 emission factors.

5.2. Comparison by sector

5.2.1. AFOLU sector overall difference

Fig. 6 presents the overall gap in GHG emission quantities of AFOLU sector using 2006 and 1996 GLs. It is noted that the gap for CH_4 emissions is smaller, but significant for CO_2 and N_2O emissions over the entire time series. On the other hand, for 2010–2017 the CH_4 emissions estimates by 2006 GLs were higher than 1996 GLs and turned out to be lower for 1994–2009. A sudden increase in gap is also observed for CO_2-eq emissions between both GLs after 2008.

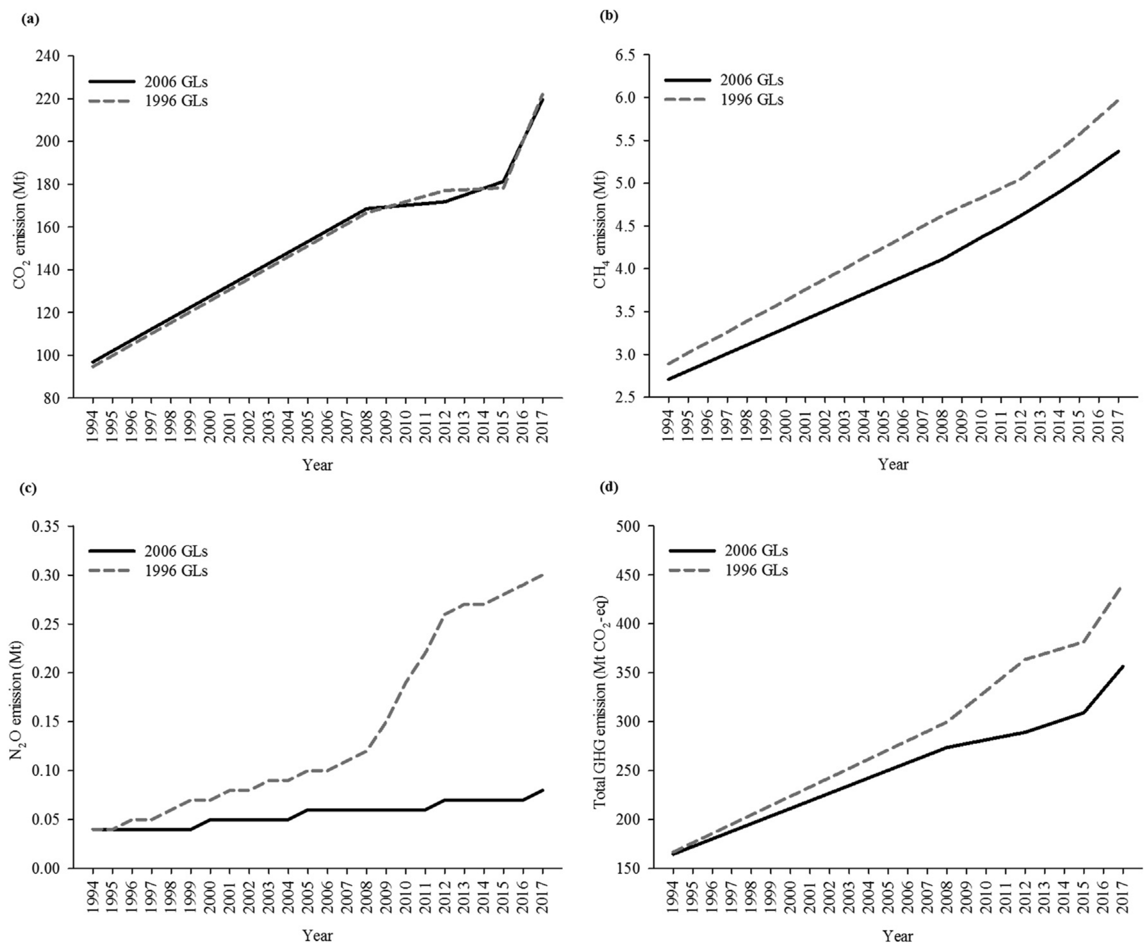

Fig. 4. National GHG emissions overall gap during 1994−2017 of (a) CO_2, (b) CH_4, (c) N_2O and (d) CO_2-eq in Pakistan, 2006 vs. 1996 GLs.

In general, there could be following possible reasons: i) the CH_4 emission factors for dairy and non-dairy cattles (enteric fermentation) are higher in 2006 GLs; ii) there is a great revision by region in CH_4 emission factor for manure management in 2006 GLs; iii) change in default emission factors and default fraction of total annual nitrogen excretion for direct N_2O emissions from manure management in 2006 GLs; and iv) possible use of different activity data sources in estimates based on 1996 GLs.

5.2.2. AFOLU sector sub-sectoral differences

5.2.2.1. Enteric fermentation and manure management. Figure A1 presents the sub-sectoral (enteric fermentation and manure management) difference in emission quantities of CH_4, N_2O and CO_2-eq between 2006 and 1996 GLs. Enteric fermentation and manure management are considered under the source category − livestock according to the 2006 GLs. Their emissions were calculated for each species or livestock category by multiplying number of animals with the species-specific emission factor for enteric fermentation and manure management. CH_4 was the only GHG produced by animals under enteric fermentation. Nonetheless, under manure management two GHGs − CH_4 and N_2O were estimated. To assess N_2O emissions from manure management, two types of activities were considered following the 2006 GLs − direct and indirect N_2O emissions.

It is noticed that 2006 GLs based CH_4 emissions from enteric fermentation across entire time series were higher than the 1996 GLs (Fig. A1) due to higher default emission factors in the 2006 GLs for dairy and non-dairy cattle under enteric fermentation. The 2006 GLs provide significant revision by region in the CH_4 emission factor for manure management as compared to the 1996 GLs. The 2006 GLs based CH_4 emissions from manure management were lower than the 1996 GLs (Fig. A1) as the updated emission factors in 2006 GLs for CH_4 were lower for most of the species compared to 1996 GLs. Table A7 provides the comparison of CH_4 emissions factors for enteric fermentation and manure management between both GLs.

Figure A1 also presents zero value for N_2O emissions from manure management by 1996 GLs (might be not estimated) for the year 1994. Nevertheless, the 1996 GLs based N_2O values for remaining years (1995−2017) observed higher than the 2006 GLs. This is possibly due to change (decrease) in default emission factors for different manure management systems (such as solid storage and poultry manure without litter) and default fraction of total annual nitrogen excretion in

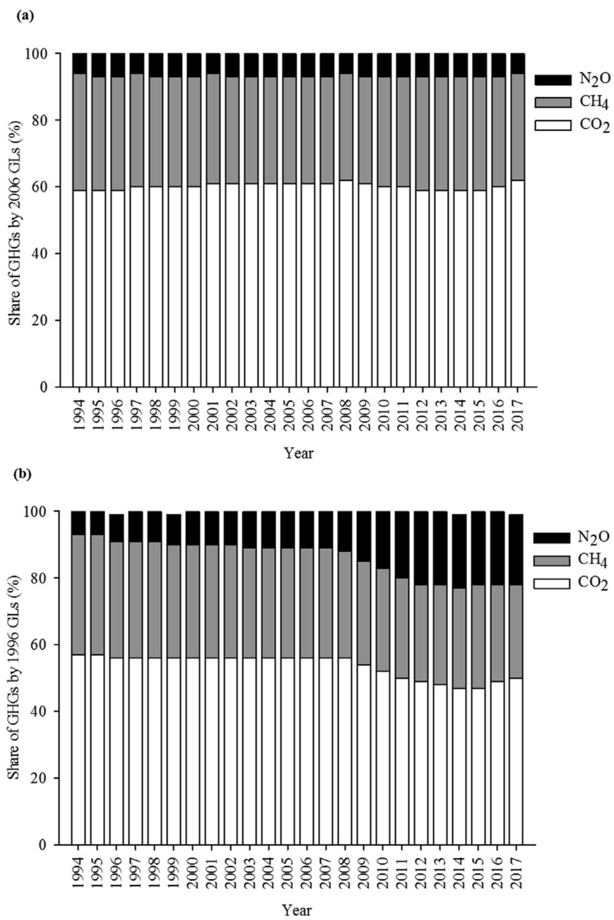

Fig. 5. GHG emissions percentage share during 1994−2017 in Pakistan (a) by 2006 GLs and (b) by 1996 GLs.

2006 GLs. It should be noted that the direct and indirect N_2O emissions were estimated separately in their respective categories according to the 2006 GLs. Individual N_2O emissions calculated by 2006 GLs were then summed up to get total N_2O emissions from manure management as compared to the 1996 GLs based estimates. Total CO_2-eq emissions from manure management for 1996 GLs were higher compared to the 2006 GLs for whole time series.

5.2.2.2. Agricultural soils, crop residue burning, and rice cultivation. Figure A2 presents the gap in emission quantities for agricultural soils and crop residue burning categories (under AFOLU sector) between 2006 and 1996 GLs. The N_2O emissions which arises naturally through the process of nitrification and denitrification, was the only GHG emitted from agricultural soils. The emissions were calculated considering the anthropogenic addition of nitrogen (in the form of chemical or organic fertilizers) to the agricultural soils following 2006 GLs. Considerable difference was noted in N_2O emissions from agricultural soils after the application of 2006 GLs. The 2006 GLs show lower emission quantities of N_2O compared to the 1996 GLs due to more refined methodology and improved default emission factors in 2006 GLs for agricultural soils. On the other hand, CH_4 and N_2O were released from the crop residue burning category. Typically, the emission calculation methodology for the crop residue burning depends on the region, crop type, crop management system, and the annual activity data. Four crops − sugarcane, wheat, rice, and maize were covered under crop residue burning for emission estimation. Further, following the 2006 GLs, a standard 10% of the total harvested area was counted as crop residue burnt area. From 1994 to 2011, the 1996 GLs present lower CH_4 emission quantities from crop residue burning than 2006 GLs. It can be explained by the accounting of smaller number of crop types in 1994 and 2008 inventory (based on 1996 GLs) compared to other years' emission inventories. However, the difference in N_2O emissions from crop residue is apparently associated with the improved default parameters (such as the total harvested area burnt) in 2006 GLs.

Fig. A3a shows the difference in emission quantities from the rice cultivation (under AFOLU sector) between 2006 and 1996 GLs. CH_4 is the only GHG emitted from the rice cultivation which occurs due to the anaerobic decomposition of organic material in flooded rice fields. The figure presents lower emission quantities of CH_4 from rice cultivation for 2006 GLs compared to the 1996 GLs. It could be due to the revised default emission as well as scaling factors derived in 2006 GLs from the analysis of latest available data. The rice cultivation period (time from planting to harvesting) was considered long (140−160 days) as the rice season in Pakistan normally spans from June to October (Nawaz et al., 2017).

5.2.2.3. Forestry sector. Figure A3b demonstrates the difference between 2006 and 1996 GLs in emissions from the forestry sector (under the AFOLU). CO_2 is the only GHG released (no removal of CO_2) from Pakistan's forestry sector. It is estimated by applying the gain-loss method, which is based on values of annual change in biomass derived from estimates of biomass gain and loss (IPCC, 2003, 2006). First, it calculates the annual gain in biomass carbon stocks due to total (includes above-ground and below-ground biomass) biomass growth by taking into account the area under each forest category. As a next step, the annual decrease in biomass carbon stocks due to biomass loss based on annual carbon loss due to industrial roundwood (logs) removals and fuelwood removal is calculated. The difference between annual loss and annual gain in biomass carbon stocks gives the CO_2 emissions (if value is negative) and removals (if value is positive). Although the difference in forestry sector CO_2 emission appear less significant (almost linear trend) between two GLs, 2006 GLs showed lower emission quantities compared to the 1996 GLs. The main explanation for this may be the comprehensive recalculation of activity data (in 2006 GLs based estimates) relating to the area under different forest categories, the annual volume of industrial roundwood (logs) removals, and the annual volume of fuelwood removal, based on national statistics (MoF, 2009; 2011; 2014; Zaman and

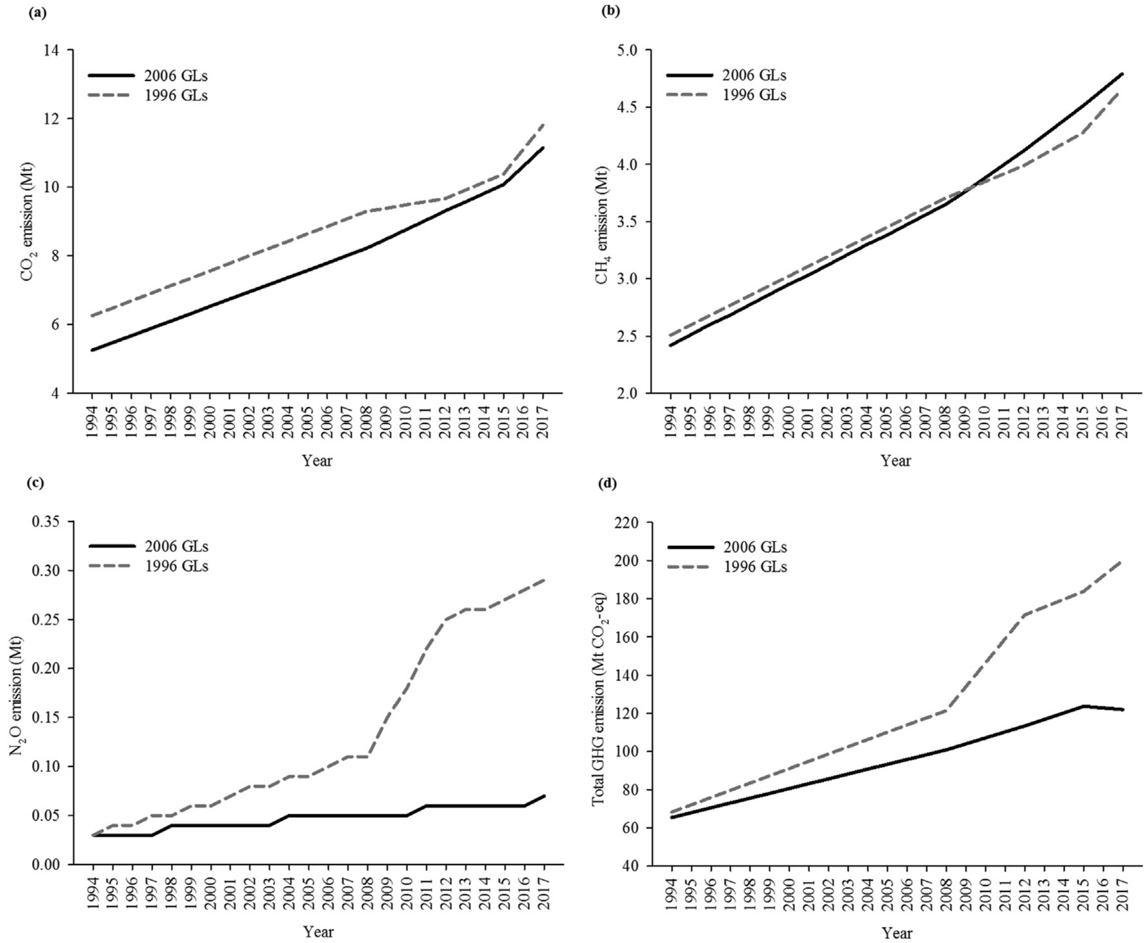

Fig. 6. AFOLU sector overall gap during 1994−2017 of (a) CO_2, (b) CH_4, (c) N_2O, and (d) CO_2-eq emissions in Pakistan, 2006 vs. 1996 GLs.

Ahmad, 2012), international data sources (FAO, 2009, 2010, 2015, 2019), and expert judgment.

5.2.3. Waste sector overall and sub-sectoral differences

Figure 7 displays the difference in emission quantities from the waste sector between 2006 and 1996 GLs. A notable gap was noticed for CH_4 and N_2O emissions from the waste sector in the entire time series. Similarly, a sharp rise in CO_2-eq emissions was observed after the year 2008 for the 1996 GLs due to the discrepancies associated with data sources for the activity data (in 1996 GLs based estimates) for different years with regard to waste generation per capita, fraction to CH_4, and CH_4 rate constant. However, in the 2006 GLs based estimates the waste generation value has been adjusted based on updated default values in IPCC FOD model (IPCC, 2006) and other available sources. Further, the 2006 GLs based emission trend revealed steadiness while the trend based on the 1996 GLs indicates deviations for different years. The overall cause for this is the refinement of methods and improved default emission factors or default parameter in 2006 GLs compared to the 1996 GLs.

Figure A4 displays the sub-sectoral (SWDS and WWTD) difference in emission quantities of CH_4, N_2O and CO_2-eq between the 2006 and 1996 GLs. The new Tier 1 (FOD) method, with improved default activity data, was applied for CH_4 emissions from the SWDS by following the 2006 GLs. On the other hand, the old default mass-balance method was used in 1996 GLs which is strongly opposed in the 2006 GLs. The 1996 GLs based inventories simply covered municipal solid waste (MSW) under SWDS while 2006 GLs also define additional sites such as sewage sludge and industrial solid waste. Therefore, to maintain the consistency for comparability with 1996 GLs, CH_4 emissions from MSW based on urban population data (MoF, 2008, 2012, 2015, 2017) were calculated following the 2006 GLs. The most important factor that affected the difference in CH_4 emissions between the both GLs is the ‘per capita waste generation per year’. The 1996 GLs show lower CH_4 emission quantities from MSW compared to the 2006 GLs for the years 1994 and 2008 (Fig. A4a). It happens due to the use of lower values for two parameters (fraction to CH_4, and CH_4 rate constant k) compared to 2006 GLs for these two years. The fraction to CH_4 was assumed 0.34 in 1996 GLs as compared to 0.50 in 2006 GLs whereas CH_4 rate constant (k) was assumed ‘0.03’ in 1996 GLs as compared to 0.09 in 2006 GLs. With regard to CH_4 and N_2O emissions from the WWTD, 1996 GLs based estimates show significant variation for the years 1994 and 2008 from the 2006 GLs estimates. Further, the 2006 GLs

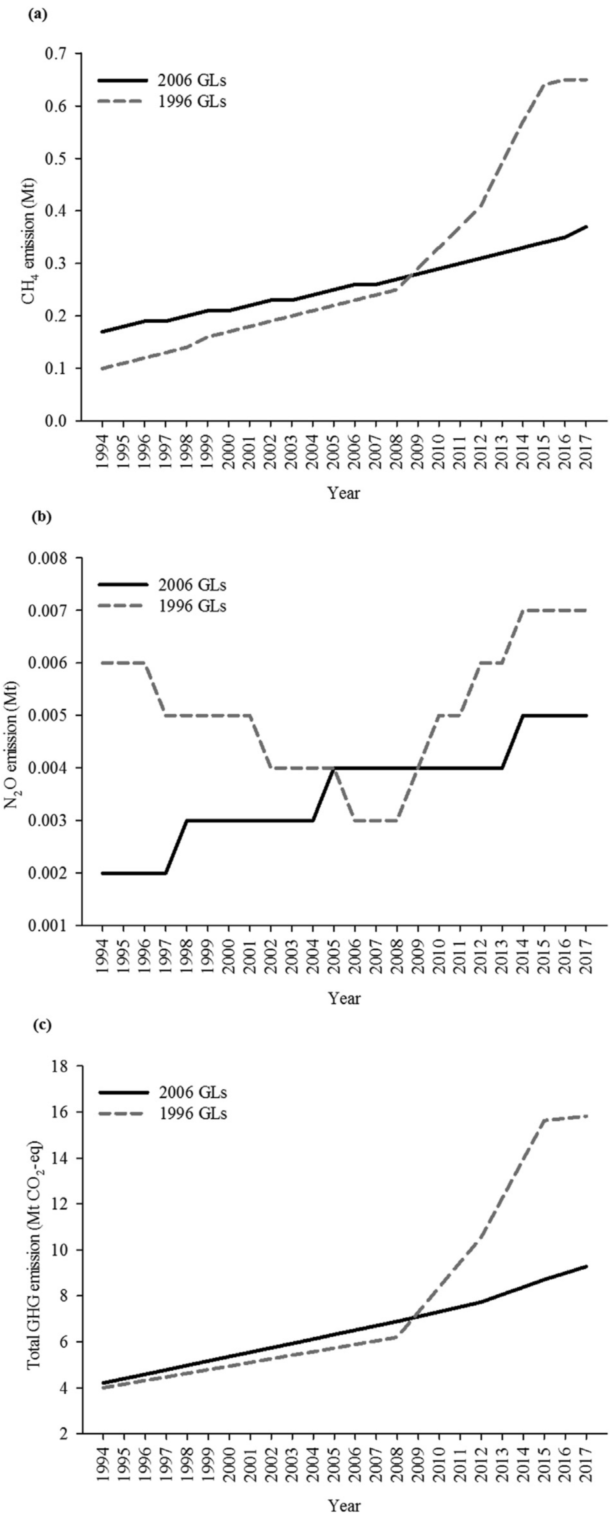

Fig. 7. Waste sector overall gap during 1994–2017 of (a) CH_4, (b) N_2O and (c) CO_2-eq emissions in Pakistan, 2006 vs. 1996 GLs.

based CO_2-eq emission quantities are lowered than the 1996 GLs due to improved default emission factors and parameter for wastewater handling. Overall the 2006 GLs based emission estimates showed steady trend for the entire time series compared to the 1996 GLs.

6. Conclusions

In this study, an attempt was made to evaluate comparative time series (1994–2017) of the GHG inventories (AFOLU and waste sector) for Pakistan using 2006 GLs along with the national emissions trend and key category analysis. It is found that total CO_2-eq emissions from the AFOLU and waste sectors (based on 2006 GLs) show a relative difference of 19% and 6% (on average for time series (1994–2017) compared to the 1996 GLs based inventories. Furthermore, the findings revealed that by 2006 GLs the quantity of national GHG emissions is on average 10% (absolute difference in the range of 2–84 Mt CO_2-eq) than that reported by 1996 GLs over the entire period (1994–2017). The key category analysis by level assessment identified three categories (two from the energy sector and one from the AFOLU sector) that contribute 47% (nearly half) to Pakistan's national GHG emissions.

The study results are limited to the 2006 GLs Tier 1 approach because of the absence of country-specific emission factors data. Consequently, the few suggestions for future research in order to implement a higher level approach and to obtain more country representative estimates includes: improving data on species characterization for enteric fermentation (a key category); using more robust emission factors and corresponding activity data for direct N_2O emissions from managed soils; moving from the gain-loss method to the stock-difference method for estimation of forestry sector CO_2 emissions; and using the Tier 2 IPCC FOD method for solid waste disposal sites. In the current study, the GHG inventories produced are partially limited because they do not cover all the source categories and GHGs for which the 2006 GLs provide estimation methods. Only those source sectors and GHGs which were considered in the 1996 GLs based GHG inventories are taken into account. To some extent, but not fully enforced, quality assurance and quality control procedures are being applied. Similarly, the uncertainty of emission estimates (quantitatively or qualitatively) at the source level and for inventory totals in this study has not yet been assessed. Having an uncertainty analysis can help direct the research resources available to reduce the uncertainty over time and track the improvement.

This work provides a detailed and reliable time series analysis of GHG emissions from Pakistan based on updated IPCC national inventory guidelines (2006 GLs). To further enhance the reliability and accuracy of GHG inventories by integrating new sources, updated methods, and revised default emission factors, it is recommended that Pakistan should follow the 2006 GLs. However, with the implementation of the 2006 GLs, the Government of Pakistan will be expected to recalculate its baseline NDC emissions (up to 2030) compared with the base year of 2015. This will likely result in a change in the baseline emissions (and national reduction target) primarily due to a difference in the guidelines (2006 GLs instead of 1996 GLs) used to estimate emissions from base year (2015). According to the results of the present study, the estimates based on 2006 GLs (for 2015 only) suggest a 19% decrease in national GHG emissions compared to 1996 GLs considering the same source sectors and approach. Therefore, only the transition to 2006 GLs for base year emissions (from 1996 GLs) shows a significant decrease in total GHG emissions, which will obviously further affect Pakistan's baseline emissions and reduction goals for NDCs. Finally, the transition to 2006 GLs would certainly facilitate policymakers to devise and communicate rigorous, transparent and comparable near-term (NDCs) and long-term low GHG emission development strategies (LT-LEDS) under the Paris Agreement for Pakistan.

Declaration of competing interest

The authors declare no conflict of 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.2021.01.003.

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