GLOBAL METHANE EMISSION: PATTERNS AND KUZNETS HYPOTHESIS

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Abstract: The paper seeks to find out the structure, nature and patterns of global methane and carbon di-oxide emissions from 1970 to 2018.The paper endeavours to verify the Environmental Kuznets Curve hypothesis for both the global emissions for the specified period. Moreover, the paper tries to show the cointegrating relationships and long run causalities from global GDP per capita to both the global methane and carbon di-oxide emissions. Using semi log and double regression model and cointegration and VEC model the paper concludes that the global methane emission increased by 1.06% per year significantly during 1970-2018 in comparison with 1.85% per year of global CO_2 emission. Actually, global methane emission is cubic in nature whereas CO_2 emission is quadratic. The methane emission contains four upward structural breaks as against five upward structural breaks of CO_2 emission. Both of them have significant inverse S type cyclical trends in H.P. Filter model. In forecasting model of ARIMA (1,1,1) for 2050, global methane is stable and nonstationary but global CO_2 emission is stable and stationary showing convergent patterns. Both methane and CO_2 emissions have been absolutely decoupled from GDP per capita square and relatively decoupled from GDP per capita cube during 1970-2018 significantly which indicate that global methane and CO_2 emission follow Environmental Kuznets Curve hypothesis. Global methane emission is cointegrated with GDP per capita having one cointegrating equation where cointegrating equation moves to the equilibrium and CO_2 emission has two cointegrating equations which also move to equilibrium significantly, i.e. both methane and CO_2 emissions have long run causality from GDP per capita from 1970 to 2018.

Key Words: Methane emissions, CO_2 emissions, Environmental Kuznets Curve, Structural breaks, long run causality, cointegrating equation

JEL Classification Codes- C32, 052, Q43, Q54

1. INTRODUCTION

Methane is recognised as a flammable gas and is used as a fuel which contains high energy content producing heat or generates electricity. Methane is the second largest GHG contributor to human induced climate change.

The amount of methane in the atmosphere has stepped by more than doubled in the past 250 years. It has been responsible for about a fifth of global warming. During 8000000 years ago, methane concentration varied between 300 and 800 parts per billion and it was found that global methane concentration rose from 722 parts per billion in pre-industrial time to 1866 ppb by 2019 i.e. an increase by a factor of 2.5.

Methane is available from different sources such as, [i] in course of production and transport of coal, natural gas and oil, [ii] from livestock and other agricultural practices and [iii]from organic waste in municipal solid waste landfills. The share of availability of methane are as follows:[a] 60% from humans and livestock animals, [b] 40% from natural sources such as wetlands,[c] 30% from grazing animal such as cattle and sheep including livestock animals ,[d]25-34% from Fugitive emissions,[e]18% from human waste, landfill and waste water,[f]7-20% from rice production,[g] 30%from wetlands and [h] 10% from other sources.

NASA assured that the sources of global methane are as follows: Wetlands constitutes 22% followed by coal and oil mining, natural gas 19%, enteric fermentation contributes 16% followed by rice cultivation 12%. Biomass constitutes 8% and landfills constitutes 6% followed by sewage treatment and animal waste 5% each and terraces contributes only 4%.

In a 100-year time scale a tonne of methane emitted into atmosphere is 34 times warmer than carbon di-oxide while it is 85 times warmer in case of the 20-year time scale. There is over 200 times more CO_2 in atmosphere than methane although methane is more potent than CO_2. Eq-CO_2 levels are 380ppm while methane levels are 1.75ppm. Hence the amount that methane contributes in the surface is 28% more warmer than CO_2 contributes. However, methane is a short-lived climate pollutant and has an atmospheric lifetime of 8.4 years. (lifetime= the atmospheric burden divided by the sink strength). Based on the GWP(100 years span),IPCC's first Assessment Report cited that GWP of methane was 21 which increased to 23 as per second Assessment Report of IPCC for the years 2013-2017.It indicated that one tonne of methane is deemed equivalent to 23 tonnes of CO_2.In other words, one litre of CH_4 is 8.4 times as potent as one litre of CO_2.According to 100-years' time scale, GTP of methane is estimated as 13gCO_2eq/gCH_4 as against 71 under 20-year time scale. Note that the GTP20 is around 20% lower than the equivalent GWP20(87) which is 60% lower when it is measured by100-year time horizon.

According to World Bank data in 2012, China emits the highest methane emission amounting to 1752290.14kt CO_2 equivalent which is 21.86% of world methane emission followed by India amounting to 636395.82 kt i.e. 7.94% of the global methane emission and USA emits 499809.345kt of methane which is 6.23% of global methane emission.

In India,CH_4 emission has increased approximately by 2.5times during 1999-2009 and reached the value of 1084.03 Gg/yr in 2015 i.e. by 245% increase from 1999 to 2011 and 109% from 2011 to 2015.Maharashtra showed maximum CH_4 emission of 70.6Gg while Tripura showed minimum emission of 0.2Gg.A positive association was found between CH_4 and GSDP which were 0.88,0.68 and 0.80 for 1999-00,2009-10 and 2014-15 respectively. The net annual emission of CH_4 from landfill in India increased from 404Gg in 1999-2000 to 990 Gg and 1084 Gg in 2011 and 2015 respectively. The MSW generated from households is considered third major anthropogenic source of CH_4 and it constitutes 11% of total CH_4.The MSW is disposed into landfills. The per capita generation rate of MSW in India is estimated as 0.2- 0.5 kg/day. (Singh, Kumar & Roy,2018).

In this context, the paper seeks to find out the structure, nature and patterns of global methane compared to carbon di-oxide emissions from 1970 to 2018.The paper endeavours to verify the Environmental Kuznets Curve hypothesis for both the global emissions for the specified period. Moreover, the paper tries to show the cointegrating relationships and long run causalities from global GDP per capita to both the global methane and carbon di-oxide emissions.

2.LITERATURE REVIEW

Foster and Rahmstort (2011) analysed global temperature rise using three surface temperature records such as NASA/GISS,NOAA/NCDC and HadCRU from which it was found that global warming was ranging from 0.014 to 0.018Kyr^{-1}.Schaefer(2019) analysed the revision of anthropogenic fossil fuels trend based on $\delta^{13}CH_4$ and ethane/propane ratio and revised geologic source using the preindustrial methane radiocarbon content to <16Tg/annum which challenged three fold higher inventory and $\delta^{13}CH_4$.The paper found that the estimates for a combined CH_4 climate feedback of 180Tg/annum from wetlands and permafrost exceeds present day fossil fuel CH_4 emissions(110Tg/annum) which are similar to current agricultural emission.

Jardine et al (2005) stated that methane can be removed from the atmosphere by a range of chemical and biological processes which includes tropospheric oxidation, stratospheric oxidation and uptake by soils. Oxidation of methane in the troposphere is the largest methane sink, removing 506Mt of methane per year from the global methane burden. Stratospheric oxidation of methane consumes 40Mt per year. Approximately 30Mt of methane are removed from the atmosphere annually by uptake in soils.

The study of Hausman and Raimi (2019) assessed the amount of global damage from methane emission which is roughly $75 to $100 billion whereas EPA studied that climate related damages have been estimated at $1300 to $1600 per tonne. The problem of methane leaks cannot be solved through Market forces alone while companies should have some attractive incentives to capture the escaping gas so that the people can serve competitively.

Kumari et al (2019) studied that CH_4 emission from livestock sector which led to significant rise in surface temperature. Using the IPCC Tier 1 methodology, the paper estimated CH_4 emission in India as 15.3Tg CH_4 in 2012 in which 14.20TgCH_4 or 92% is related to enteric fermentation and the rest 8 % (1.16TgCH_4) of total comes from methane management respectively. In India, at 20-year time horizon, the ΔT20 varies from $1.53 x 10^{-7}$ to 0.005mK due to Indian livestock sector. However, at 100-year time horizon, the ΔT100 varies from $7.66 x 10^{-9}$ to 0.0002mK. The states can contribute to the surface temperature response(ΔT20), ranging between $8.5 x 10^{-5}$ and $1.25 x 10^{-1}$mK in 20-year time horizon in comparison to $4.23 x 10^{-5}$ to $6.5 x 10^{-3}$ mK at 100-year time horizon. Uttar Pradesh is observed as highest surface temperature as a result of CH_4 emission while Mizoram is the lowest.

Van Dingenen et al (2018) concluded that additional health impact from O_3 premature death will rise from 40000(+12%) to 90000(+26%) within 2050 in pessimistic scenarios compared to present as a result of rise of emission by 2 to 4.5ppb. Under low emission scenario of CH4,the regional shares of global O_3 mortalities in 2050 are predicted 7.2% in Europe,3.5% in North America,2.5% in Middle East,7.5% in Central Asia,11% in East Asia,42% in South Asia ,14% in South East Asia,1.9% in North Africa,5.7% in SSA, and 2.4% in South Africa respectively .Even the percentage change in crop economic loss in 2050 in Europe will be 16% to 37% in comparison to global loss of 8% to 19% respectively.

Wang et al. (2017) empirically verified that environmental Kuznets curve is U shaped in case of N_2O and CH_4 during 1980-2009 and 1990-2009 in USA but it is inverted U shaped in case of CO_2 in relating with GDP per capita during 1960-2009 using cointegration test which were significant at 5% level.

Cruz et al(2018) estimated EKC in Argentina using data from 1970 to 2012 relating CH_4 emission and GDP per capita and agriculture through ARDL approach and found that environmental Kuznets curve is inverted U shaped having short run and long run causalities.

Benavides et al(2017) studied empirically in Austria during 1970-2012 using ARDL method among CH_4 and per capita GDP, trade openness, electricity production from renewable sources and found that CH_4 and the variables support inverted U shaped environmental Kuznets curve and also found short run and long run causalities between CH_4,trade openness and GDP per capita in Austria.

Williamson(2017) studied that both CO_2 and CH_4 emission are related to satisfy EKC hypothesis even if there are GDP per capita, mean years of schooling, government regimes (where there are 5 dummy variables),GDP shares of agriculture, industry and the inputs of electricity production(where there are three dummy variables) are assumed to be control variables in 181 countries in 2012.The paper satisfied that the EKC hypothesis of CO_2 was inverted U shaped curve but CH_4 did not although energy variables and government regimes showed significant results. The agricultural share showed highly significant which indicates that more noticeable impact on over all methane emission was observed and the significant government regime indicates that more democratic structure is likely to set growth agendas that lessen damages of GHG.

3.METHODOLOGY AND SOURCE OF DATA

The linear and nonlinear trends have been calculated from the semi-log regression model. Structural breaks have been obtained from the Bai-Perron model(2003).Minimisation of cycles were found by applying the H.P.Filter model(1997).The forecasting ARIMA(1,1,1) model was applied to show convergence or divergence from 1970 to 2050 in association with ARIMA(1,1,1) showing stationary and stability of AR and MA of global emissions during 1970-2018.Double log regression model was fitted to find out Environmental Kuznets Curve hypothesis (1955) in global methane and CO_2 emission. Johansen model(1988) was fitted to get cointegration and vector error corrections. Wald test(1943) was applied to find short run causalities and the long run causalities were verified by using the properties of cointegrating equations.

The data of global methane and CO_2 emissions have been collected from the World Bank during 1970-2018 where missing data were calculated through approximation and obtained from internet sources. The global GDP per capita in current US dollar at market prices during 1970-2018 were also collected from the World Bank.

4.OBSERVATIONS FROM THE MODELS

4.1 Temperature rise

GHGs are the main sources of global warming. Various global institutions have calculated and projected global temperature rise using long period data from time to time taking models of global warming.

Using the GISS Surface Temperature Analysis(GISSTEMP4) and applying the methodology of Foster and Rahmstorf(2011),the global surface temperature has increased at the rate of 0.0068±0.0009°C/year(2σ)during 1800-2015 where it was found that $\beta=0.0067522$, $\sigma_w=0.00012169$, $v=12.372$, $\sigma_c=\sigma_w\sqrt{v}=0.00042802$.

The trend line of temperature rise has been plotted in the Figure 1 where fitted and actual lines have been marked.

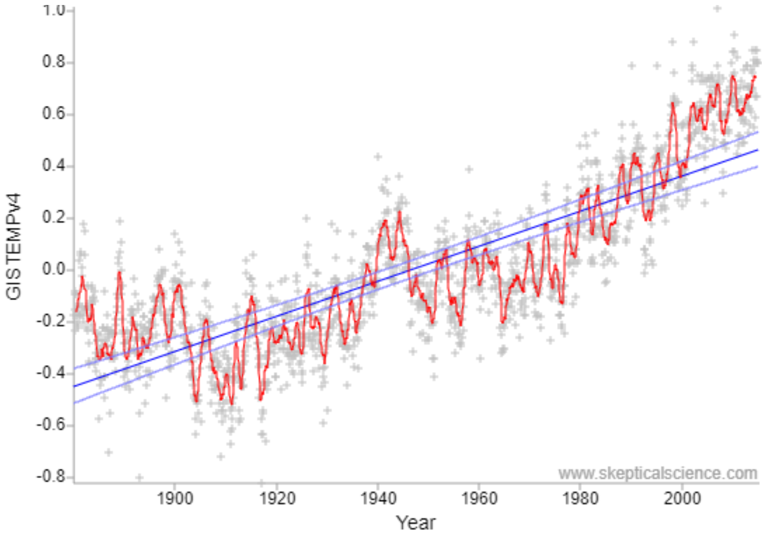


Figure 1: Temperature rise using GISSTEMPT4
Source-www.skepticalscience.com

On the other hand ,using HadCRUT4 analysis and applying the methodology of Foster and Rahmstorf(2011),the global surface temperature had increased at the rate of 0.0052± 0.0006°C/year(2σ) during 1800-2015 where it was found that β=0.0052084, σ_w=0.00094429,v=11.700, and $\sigma_c=\sigma_w\sqrt{v}$=0.00032300.The fitted line and the actual line have been depicted in Figure 2 shown below.

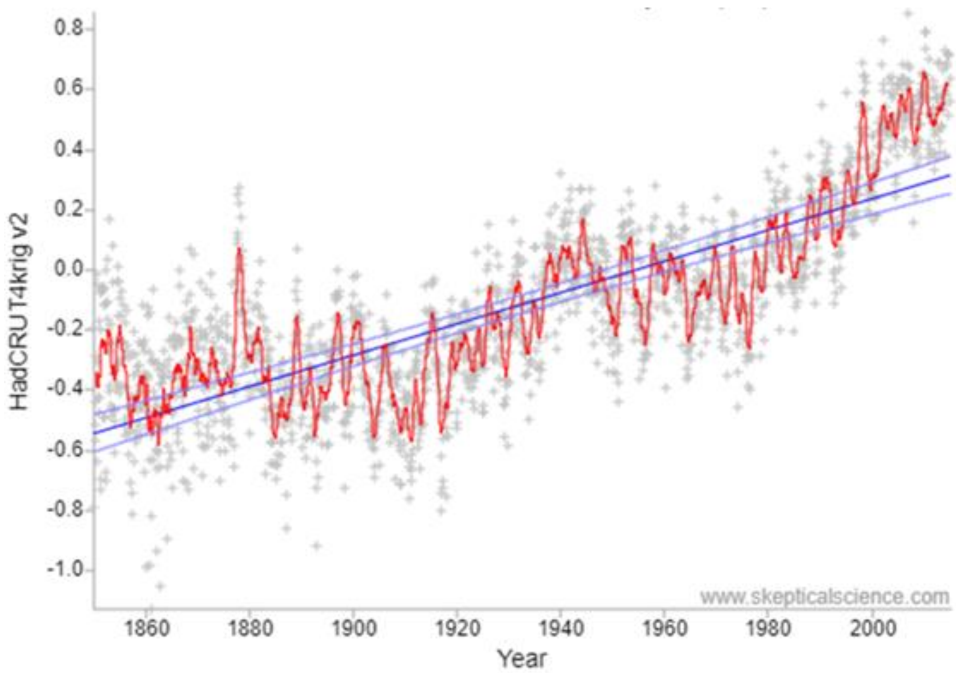


Figure 2:Temperature rise using HadCRUT4
Source-www.skepticalscience.com

4.2 Patterns of global CH_4 and CO_2

The global methane gas emission has been catapulting at the rate of 1.06 per cent/year from 1970 to 2018 which is statistically significant at 5 per cent level. The estimated trend line is given below.

$$\text{Log}(x_2)=1.6397+0.01066t$$

$$(120.65)^*(22.53)^*$$

$R^2=0.915$, $F=507.88^*$, $DW=0.47$, where x_2=methane gas emission in kt ,*=significant at 5% level.

In Figure 3, the global estimated methane gas emission is depicted and is shown upward rising steadily from left to right.

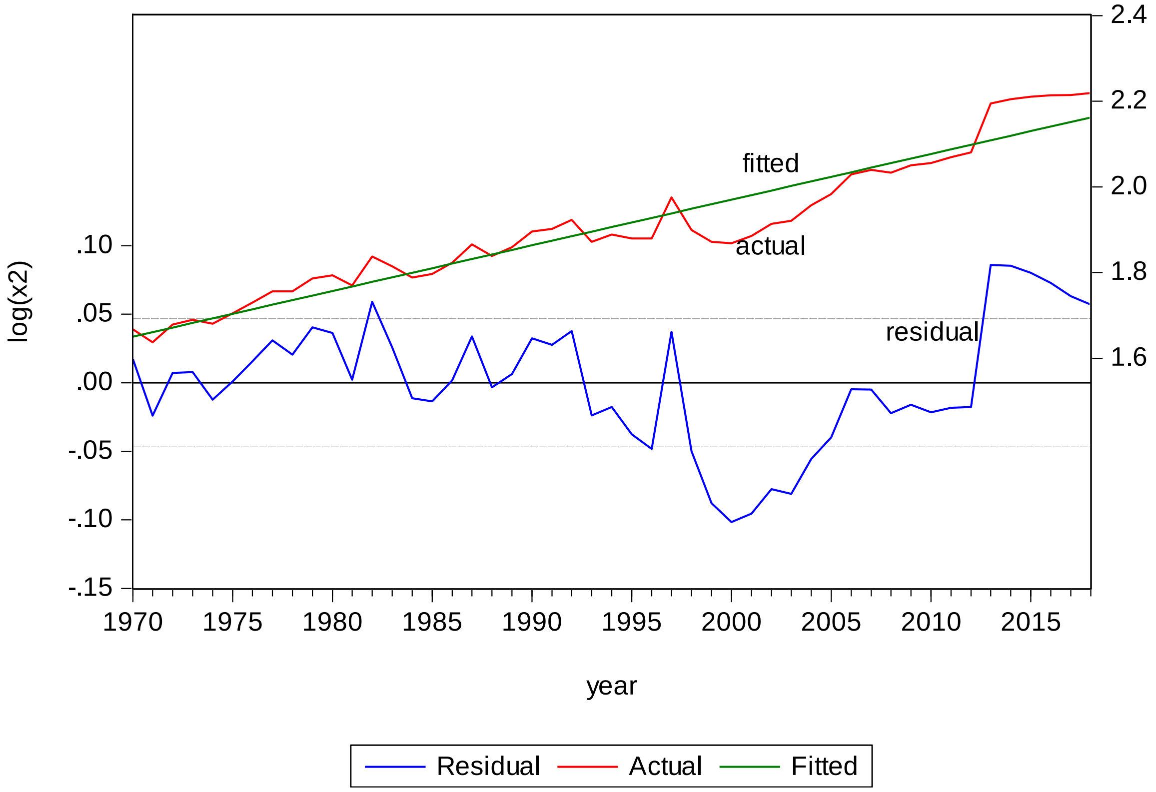


Figure 3: Estimated methane gas emission

On the other hand, global CO_2 emission has been increasing at the rate of 1.85 per cent per year significantly at 5% level from 1970 to 2018.

$$\text{Log}(x_1)=2.7036+0.01852t$$

$$(217.57)^*\ (42.81)^*$$

$R^2=0.97$, $F=1832.97^*$, $DW=0.239$, x_1=global co_2 emission in kt,*=significant at 5 per cent level.

In Figure 4, it is plotted and is shown upward rising steadily.

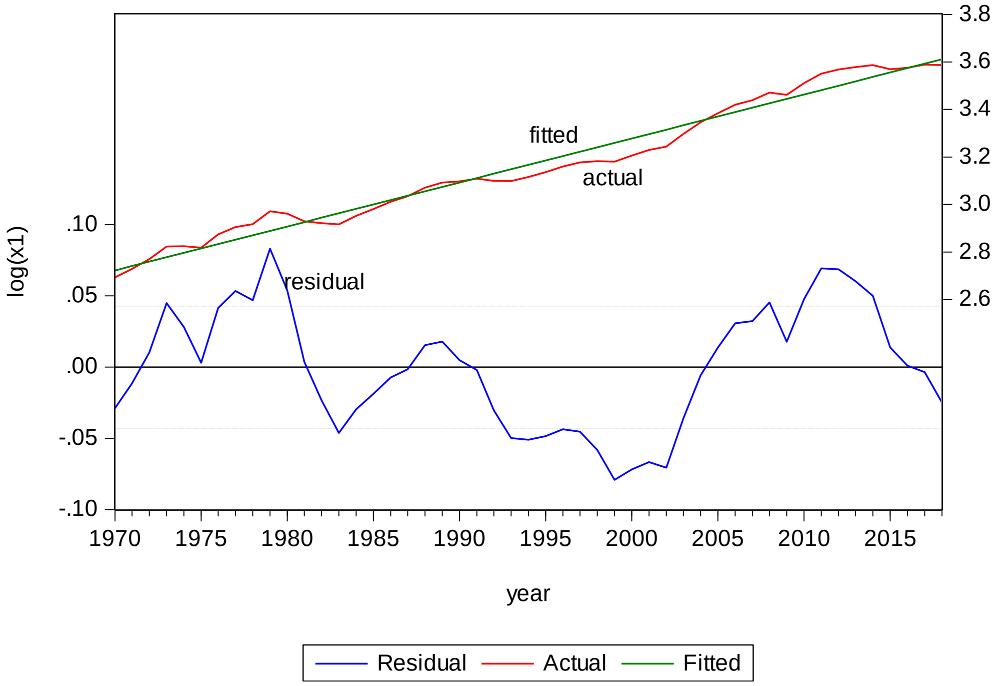


Figure 4: Estimated global co_2 emission

Global methane emission showed four upward structural breaks in 1977,1990,2005 and 2012 all of which are significant at 5% level. In Figure 5, the structural breaks have been marked and plotted.

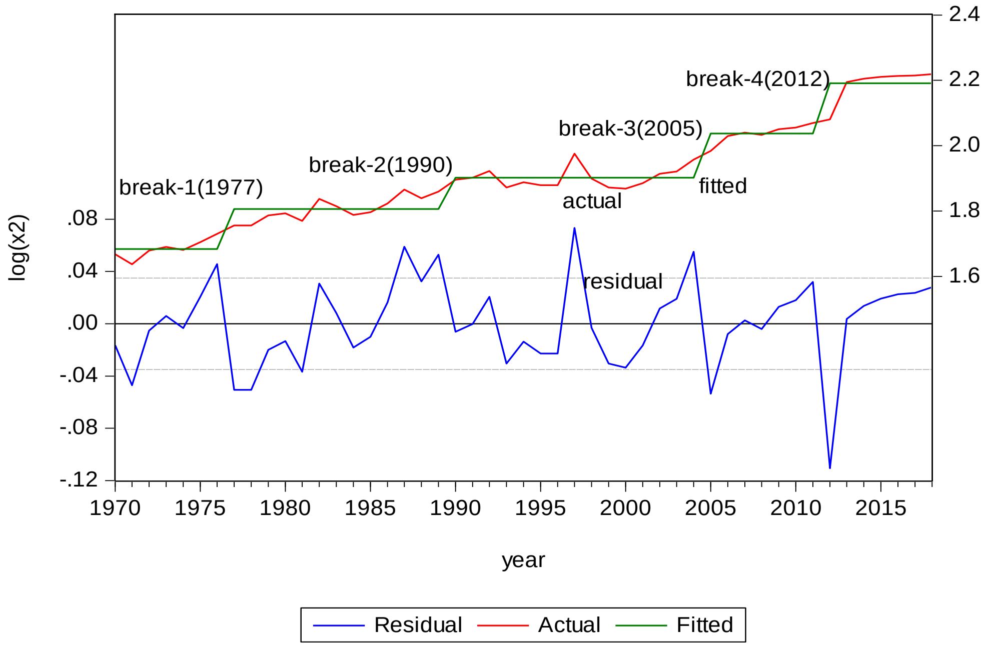


Figure 5: Structural breaks of global methane emission

On the contrary, global CO_2 emission has the property of having five structural breaks in its path from 1970 to 2018 in 1977,1987,1996,2003 and 2010 all of which are significant at 5% level and all showed upward rising. It is depicted in Figure 6 below.

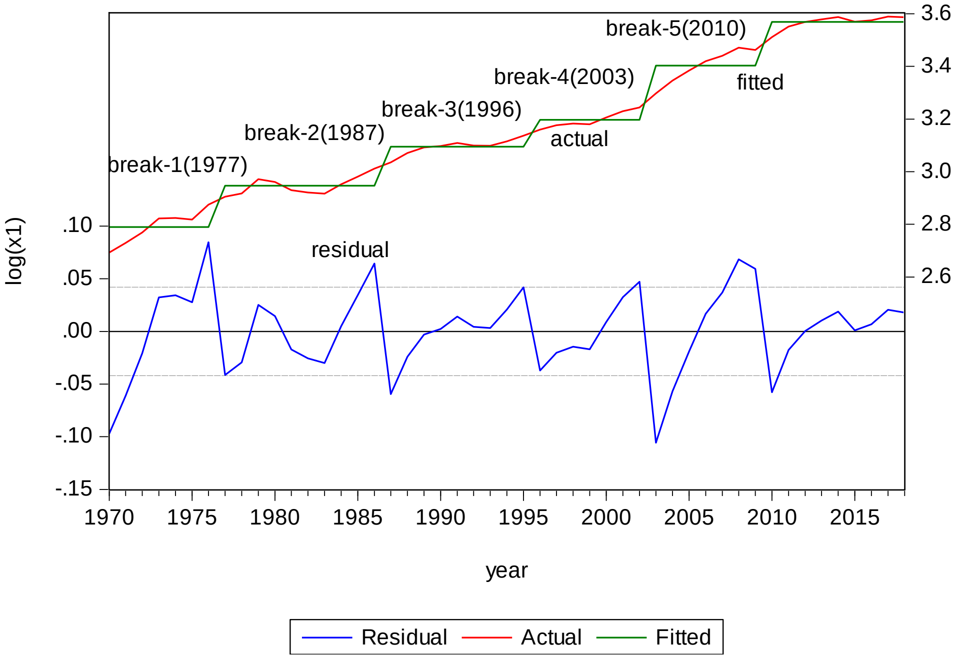


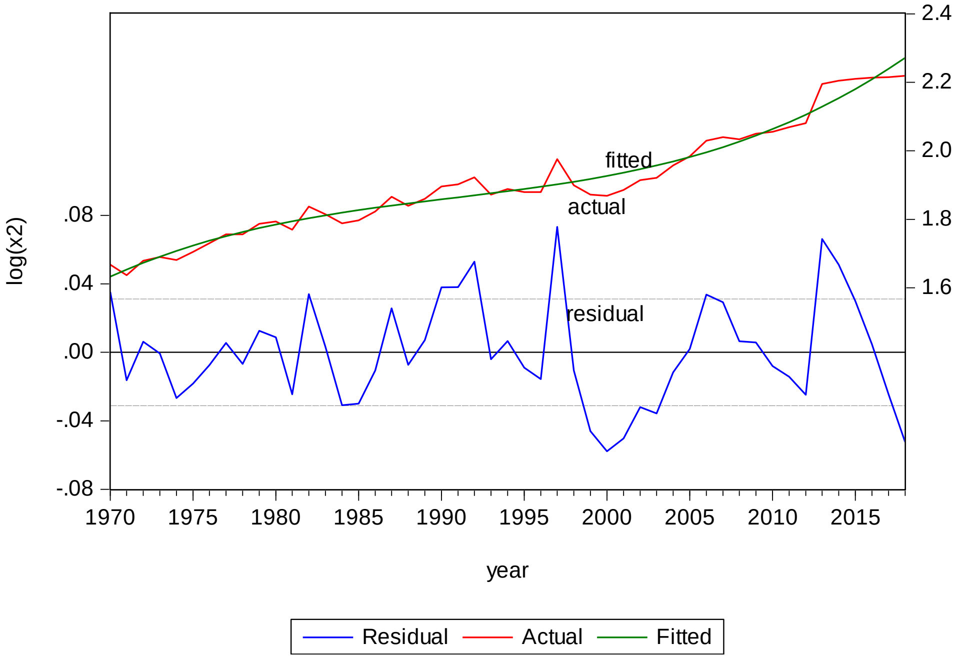
Figure 6: Structural breaks of global CO_2 emission

Actually, the time path of global methane emission is cubic which was estimated and was found as significant at 5% level.

$$Log(x_2)=1.610+0.0231t-0.00079t^2+1.23E\text{-}05t^3$$

(83.61)*(7.01)* (-5.23)* (6.11)*

R^2=0.96, F=403.17*, DW=1.14, *=significant at 5% level.



It is plotted in Figure 7 and the estimated line is an inverse S which is upward.

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Actually, the global CO_2 emission fulfils the quadratic function properties and the estimated form is given below.

$$Log(x_1)=2.748+0.013t+0.000105t^2$$

$$(159.11)^* \ (8.31)^* \ (3.41)^*$$

R^2=0.98,F=1129.95*,DW=0.314,*=significant at 5% level

This quadratic form is significant at 5% level and the nonlinear estimated line has been plotted neatly in Figure 8.

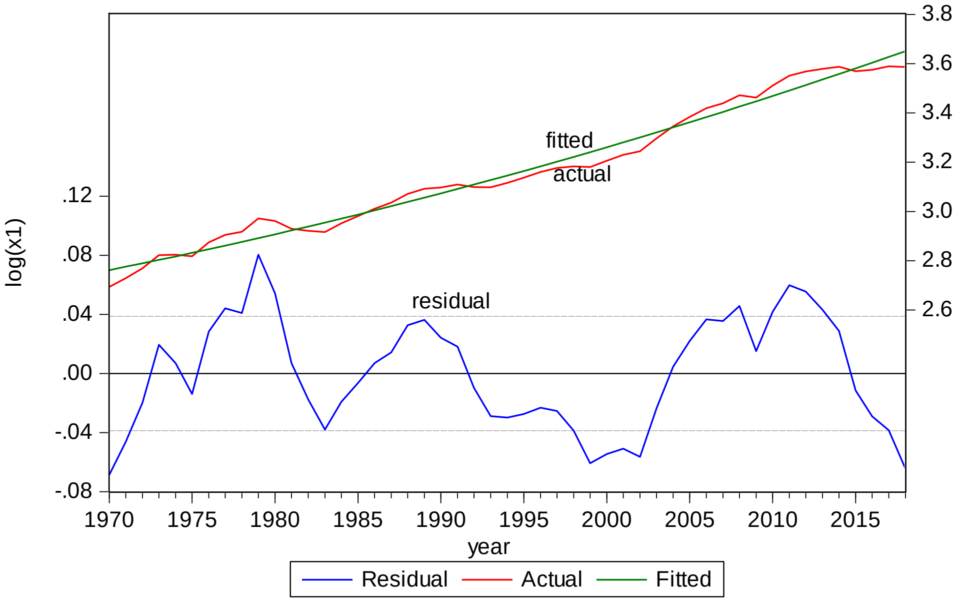

Figure 8: Quadratic form of global CO_2 emission

If the cyclical paths of global methane emission from 1970 to 2018 is minimised into trend line through H.P. Filter Model assuming λ=100 then the trend line is as good as inverse S which is upward rising and is significant at 5% level. It is shown in Figure 9.

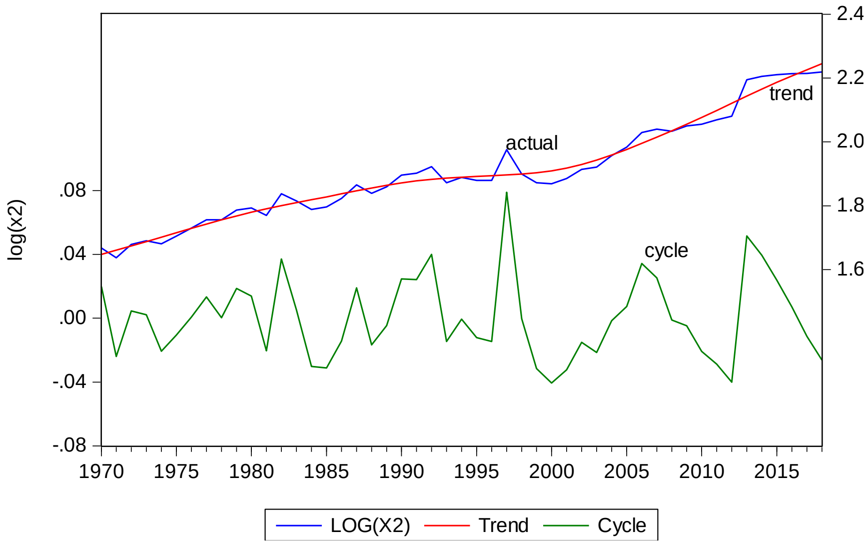

Figure 9: Methane emission in H.P. Filter model

In the H.P. Filter model, it was found that the minimisation of cycles of CO_2 emission is estimated as nonlinear trend which is upward and partially inverse S.

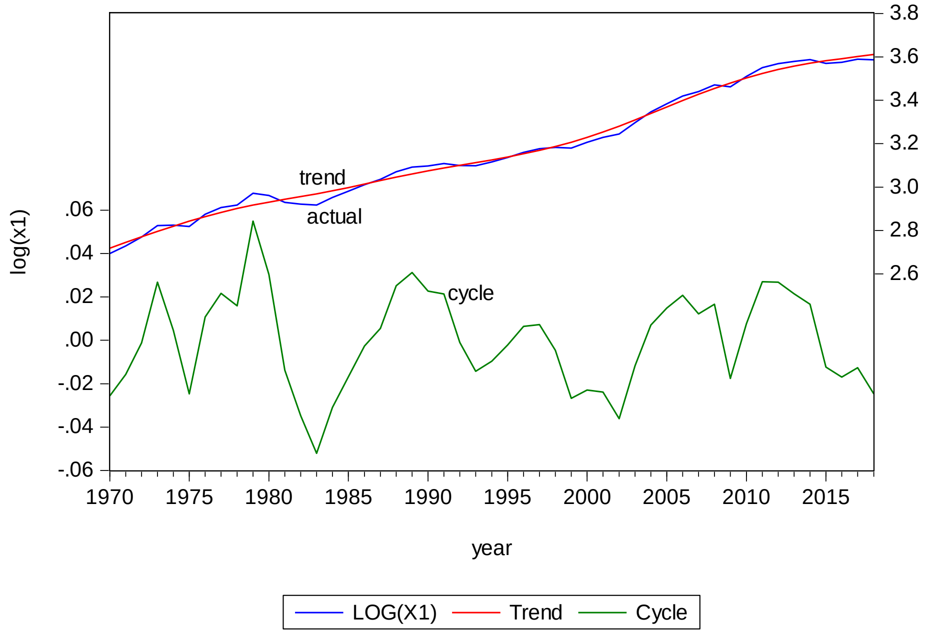

Figure 10: H.P.Filter of global CO_2 emission

ARIMA (1,1,1) model for estimating global methane emission from 1970 to 2018 is shown below.

$$Log(x_2)=1.9363+0.9912log(x_2(-1))+\varepsilon_t-0.040338\varepsilon_{t-1}$$

(8.62)* (82.31)* (-0.288)

SC=-172.86, AIC=-180.43, AR root=1.0088, MA root=27.79, z values are in parenthesis, *=significant at 5% level.

It implies that autoregressive process is significant and convergent but moving average is convergent and insignificant so that the model is unstable and nonstationary.

The forecasting ARIMA model of methane emission for 2050 is convergent and significant where $log(x_2)$ at 1970=1.6677 and $log(x_2)$ at 2050=2.1496. In Figure11 the forecast model is depicted where the significant convergent part is marked by vertical lines.

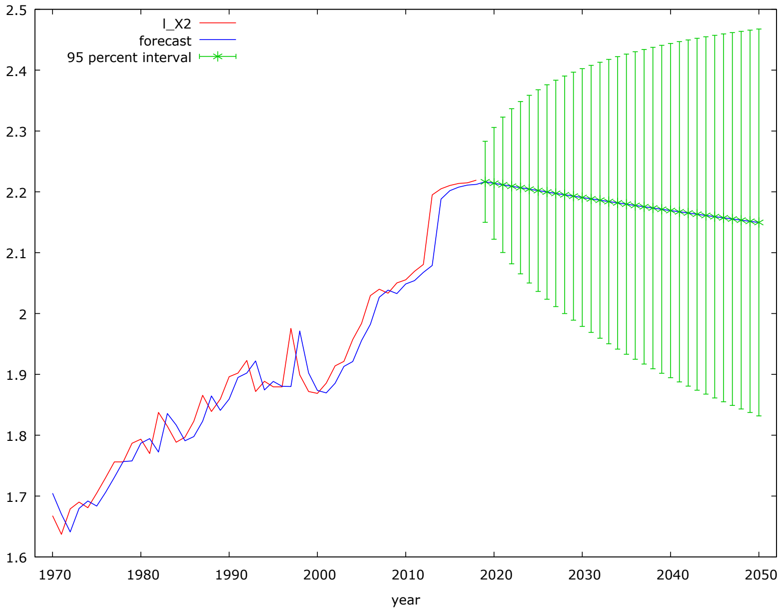

Figure 11: Estimated methane emission for 2050

The AR process of the global CO_2 emission from 1970 to 2018 is convergent and significant and even the MA process is also convergent and significant. The values of AR root and MA root are 1.0037 and -1.68, thus the model is unstable but stationary. The estimated ARIMA model is given below.

$$Log(x_1)=3.133+0.996log(x_1(-1))+\varepsilon_t+0.593\varepsilon_{t-1}$$

(7.60)* (194.5)* (5.00)*

SC=-208.19, AIC=-215.76, *=significant z values at 5% level.

The forecast value of $log(x_1)$ at 2050 is 3.534 in comparison to $log(x_1)$ at 1970=2.6932. The forecasting model of ARIMA (1,1,1) for 2050 is converging and is found as significant at 5% level which is plotted in Figure 12 in which the region of convergence is distinctly visible by the vertical lines.

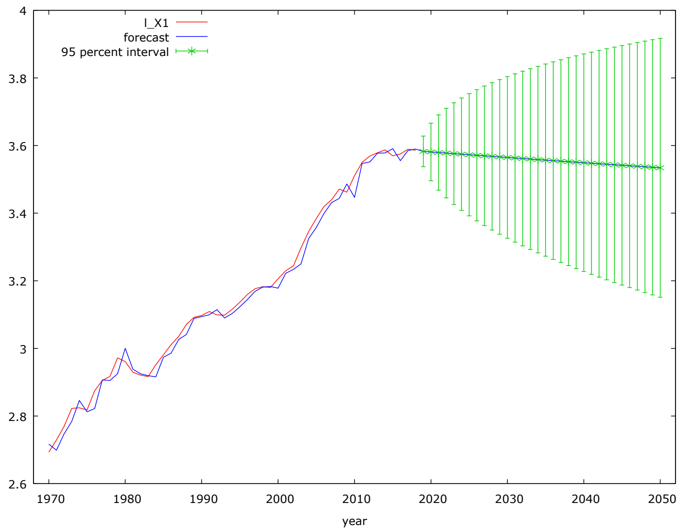

Figure 12: Forecast global CO_2 emission

4.3 Environmental Kuznets Curve Hypothesis

The following estimated equation between global methane emission in Kt CO_2 eq.(x_2) and the global GDP per capita(y) during 1970-2018 have been done through the Kuznets Hypothesis.

$$Log(x_2)=-24.62943+10.1143log(y)-1.3034log(y)^2+0.0565log(y)^3$$

(-3.39)* (3.72)* (-3.86)* (4.07)*

R^2=0.949,F=281.89*,DW=0.94,SC=-3.52,AIC=-3.67,*=significant at 5% level.

The estimate indicates that global methane emission showed absolute and relative decoupling from the global GDP per capita from 1970 to 2018 because $\delta log(x_2)/\delta log(y)$ =10.114>1 which means there is no decoupling from GDP per capita , $\delta log(x_2)/\delta log(y)^2$=-1.3034 <0 which implies that there is absolute decoupling from GDP per capita square, and $\delta log(x_2)/\delta log(y)^3$=0.0565 >0<1 which showed that there is relative decoupling from GDP per capita cube. Therefore, it follows the Environmental Kuznets Curve hypothesis. In Figure13, the EKC is inverse U shaped.

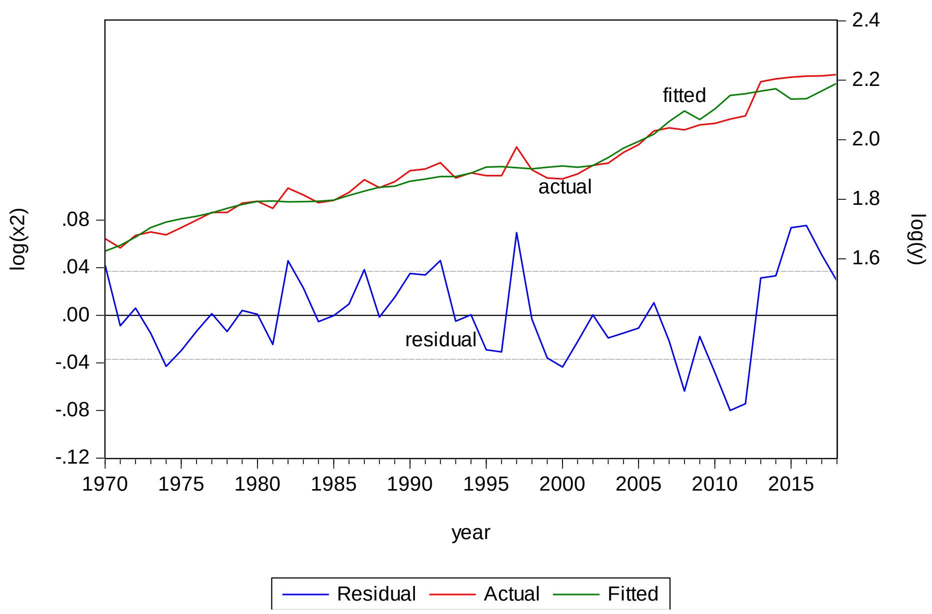

Figure 13: EKC of Methane emission

The above analysis contains autocorrelation problem although the estimation is highly significant. After eliminating the autocorrelation problem, estimated equation is as follows.

$$Log(x_2)=-16.278+6.459log(y)-0.8203log(y)^2+0.0349log(y)^3+0.573log(x_2(-1))$$

(-2.318)* (2.44)* (-2.49)* (2.57)* (5.33)*

R^2=0.96, F=343.83*, DW=2.19, SC=-3.97, AIC=-4.17, *=significant at 5% level.

Since, $\delta log(x_2)/\delta log(y)$=6.459>1 which means that there is no decoupling from GDP per capita , $\delta log(x_2)/\delta log(y)^2$= -0.8203<0 which implies that there is absolute coupling from GDP per capita square, and $\delta log(x_2)/\delta log(y)^3$=0.0349 >0<1 which showed that there is relative decoupling from GDP per capita cube.

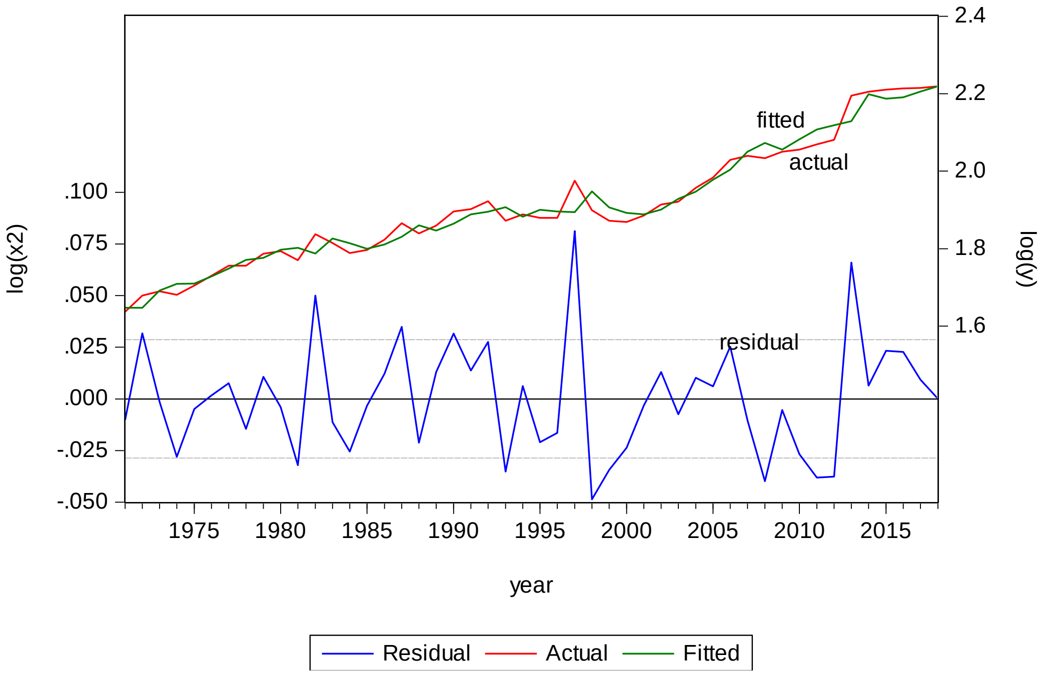

Figure 14: EKC after autocorrelation

Therefore, it follows the Environmental Kuznets Curve hypothesis. In Figure 14,the EKC is inverse U shaped which is more perfect than the previous curve after omitting the autocorrelation problem.

The estimated equation between global CO_2 emission and global GDP per capita during 1970-2018 has been given below.

$$Log(x_1)=-16.952+7.7309log(y)-1.0302log(y)^2+0.0469log(y)^3$$

(-3.18)* (3.87)* (-4.16)* (4.60)*

R^2=0.99, F=1542.86, DW=0.62, SC=-4.14, AIC=-4.29, x_1= global co_2 emission in kt, y=global GDP per capita.

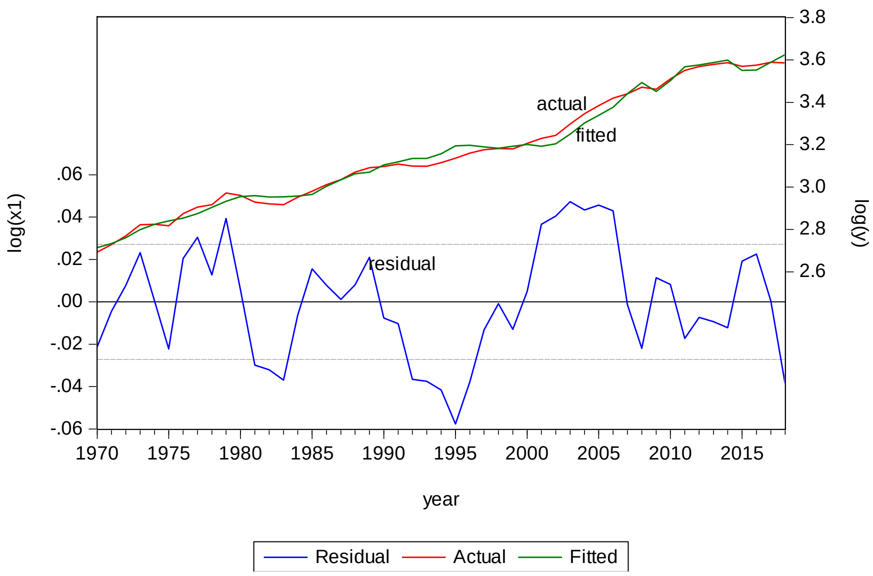

Figure 15: Decoupling CO_2 from global GDP per capita

Since $\delta log(x_1)/\delta log(y)=7.7309>1$ therefore global co_2 emission has no decoupling from global GDP per capita ,and $\delta log(x_1)/\delta log(y)^2=-1.0302<0$ therefore there is absolute decoupling from global GDP per capita square, and $\delta log(x_1)/\delta log(y)^3=0.0469>0<1$, therefore there is relative decoupling from global GDP per capita cube. It means that the Environmental Kuznets Curve hypothesis is satisfied and EKC is likely to be an inverse U shaped which is plotted in Figure 15 above.

4.4 Cointegration and Vector Error Correction Analysis

Johansen cointegration test assures two cointegrating equations in Trace statistic and Max Eigen statistic among the variables of global methane emission, global GDP per capita, global GDP per capita square and global GDP per capita cube respectively during 1970-2018.The statistic are significant at 5% level.

Table 1: Johansen cointegration test

Hypothesised no of CEs	Eigen value	Trace statistic	0.05 critical value	Probability**
None *	0.699585	87.81698	47.85613	0.0000
At most 1 *	0.363478	31.29518	29.79707	0.0334
At most 2	0.183129	10.06356	15.49471	0.2759
At most 3	0.011774	0.556652	3.841466	0.4556
		Max Eigen statistic		
None *	0.699585	56.52181	27.58434	0.0000
At most 1 *	0.363478	21.23162	21.13162	0.0484
At most 2	0.183129	9.506908	14.26460	0.2464
At most 3	0.011774	0.556652	3.841466	0.4556

Source-Calculated by author ,* denotes rejection of the hypothesis at the 0.05 level, **=MacKinnon-Haug-Michelis (1999) p-values.

The estimated VECM is given in the Table 2 where $dlog(x_2)$, $dlog(y)$, $dlog(y)^2$ and $dlog(y)^3$ are not significantly related with each other during two period lags.

Table 2: Estimated VECM of global methane emission

Error Correction:	$d(log(x_2))$	$d(log(y))$	$d(log(y)^2)$	$d(log(y)^3)$
CointEq1	-0.317559	-0.027262	-0.927432	-18.03419
	[-2.79189]*	[-0.15023]	[-0.29548]	[-0.43945]
CointEq2	-2.734345	-6.498442	-90.32880	-944.5802
	[-0.91431]	[-1.36200]	[-1.09456]	[-0.87542]
$d(log(x_2(-1)$	-0.174826	0.104263	2.015508	28.92611
	[-1.22296]	[0.45716]	[0.51093]	[0.56083]
$d(log(x_2(-2)$	-0.134444	-0.230246	-3.811612	-47.68548
	[-0.97637]	[-1.04808]	[-1.00313]	[-0.95983]
d(log(y(-1))	-18.94648	-18.08600	-318.3899	-4170.136
	[-1.15843]	[-0.69313]	[-0.70547]	[-0.70669]
d(log(y(-2))	-14.55283	-19.08519	-303.0239	-3707.286
	[-1.06546]	[-0.87582]	[-0.80397]	[-0.75228]
$d(log(y(-1)^2$	2.365786	2.442808	42.40188	548.8366

	[1.19917]	[0.77611]	[0.77887]	[0.77105]
d(log(y(-2))^2	1.793955	2.245960	35.90586	442.7091
	[1.06987]	[0.83956]	[0.77600]	[0.73177]
d(log(y(-1))^3	-0.097904	-0.105610	-1.814730	-23.28548
	[-1.23933]	[-0.83796]	[-0.83247]	[-0.81697]
d(log(y(-2))^3	-0.072381	-0.088770	-1.430437	-17.78701
	[-1.06056]	[-0.81528]	[-0.75955]	[-0.72236]
C	0.010745	0.043587	0.716934	8.948014
	[1.34226]	[3.41295]*	[3.24561]*	[3.09818]*
R-squared	0.367427	0.477205	0.396050	0.325496
F-statistic	2.032954	3.194781	2.295182	1.688998
Akaike AIC	-4.036939	-3.102687	2.598310	7.739691
Schwarz SC	-3.599655	-2.665403	3.035593	8.176975

Source-Calculated by author,*=significant at 5% level.

In Figure 16 the estimated dlog(x_2) is shown where the estimated line has been moving towards equilibrium because cointegrating equation tends to equilibrium.

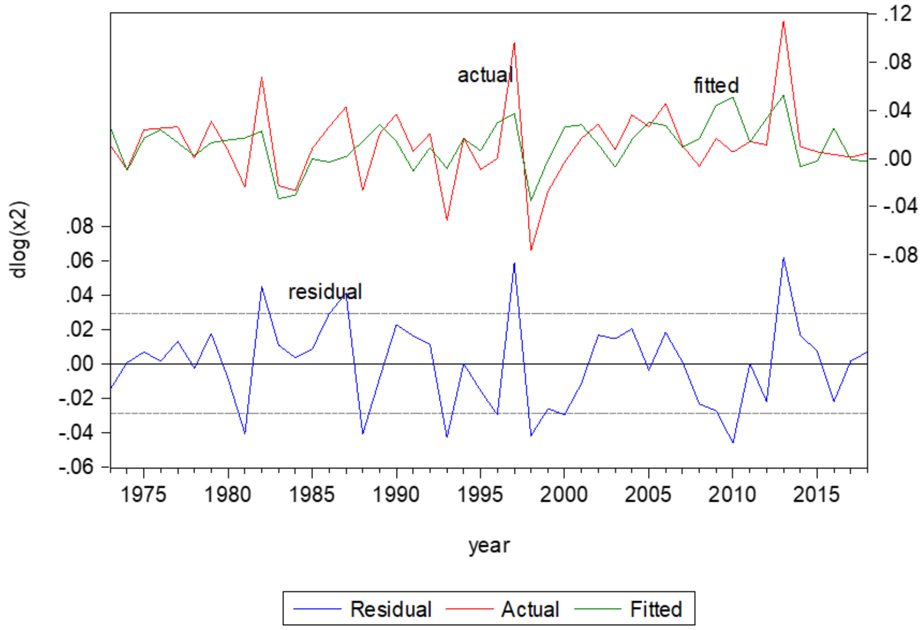

Figure 16 : Estimated dlog(x_2)

Both the estimated cointegrating equations which have been found from the system equation are given below where both of them tend to equilibrium but the first equation is significant and the second equation is insignificant. It indicates that there are long run causalities to global methane emission from square and cube of global GDP per capita in which square of global GDP per capita produces relative decoupling and cube of global GDP per capita produces absolute decoupling.

Cointegrating equation 1=-0.3175(log(x_2(-1)) + 0.1289log(y(-1))^2 -0.0116log(y(-1))^3 - 4.058

(-2.79)* (2.91)* (-3.35)*

Cointegrating equation 2=-2.734+log(y(-1)) - 0.1143log(y(-1))^2 + 0.0043log(y(-1))^3 - 2.9057

(-0.914) (-190.40)* (92.64)*

Both the cointegrating equations have been plotted in Figure 17 and they are seen as marching towards equilibrium where first one is significant.

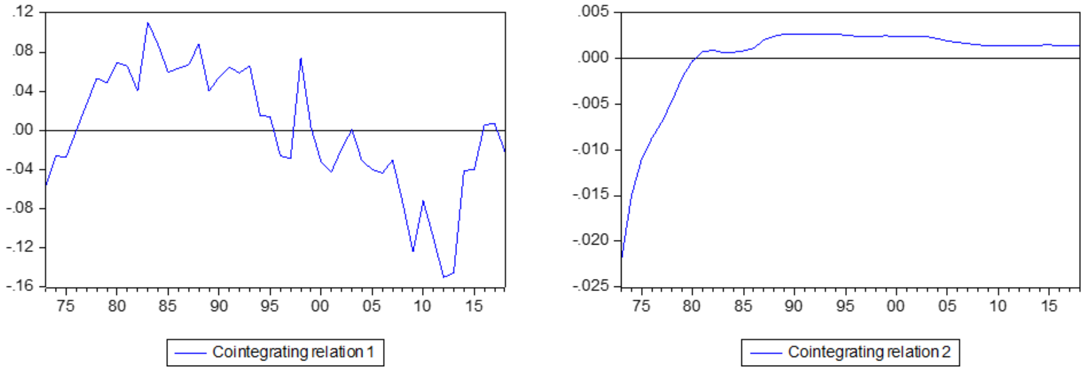

Figure 17: Cointegrating equations

This VECM is a stable and nonstationary since the model consists of unit root and all roots lie inside or on the unit circle which is shown below.

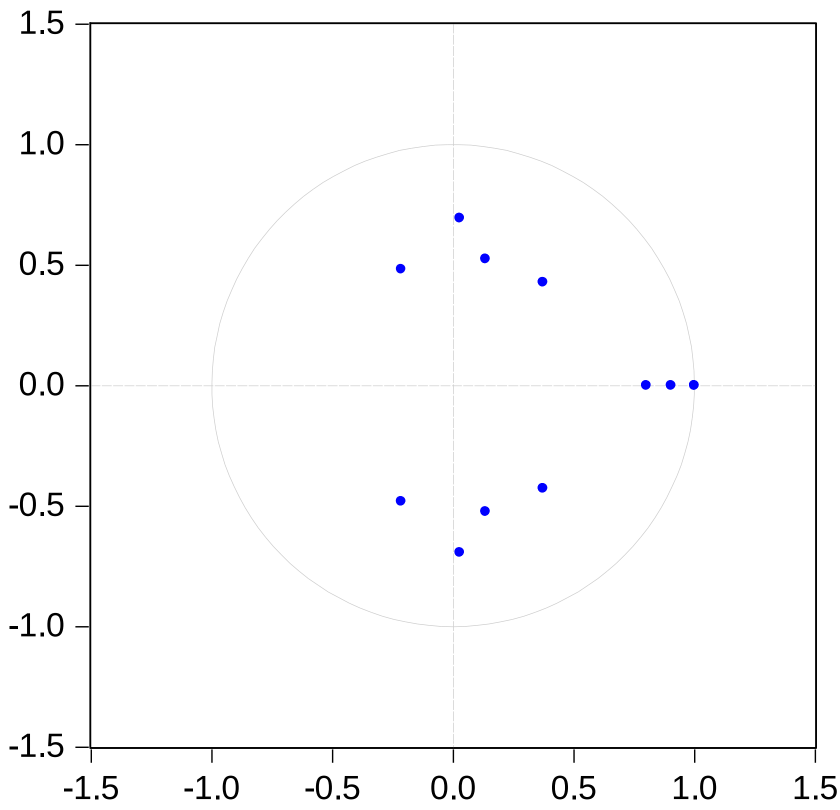

Figure 18: Unit circle

In the impulse response functions below, the third and fourth diagram in figure 19 in the first row showed that the response to Cholesky one standard deviation innovation of global methane emission to square and cube of global GDP per capita tended to reach equilibrium.

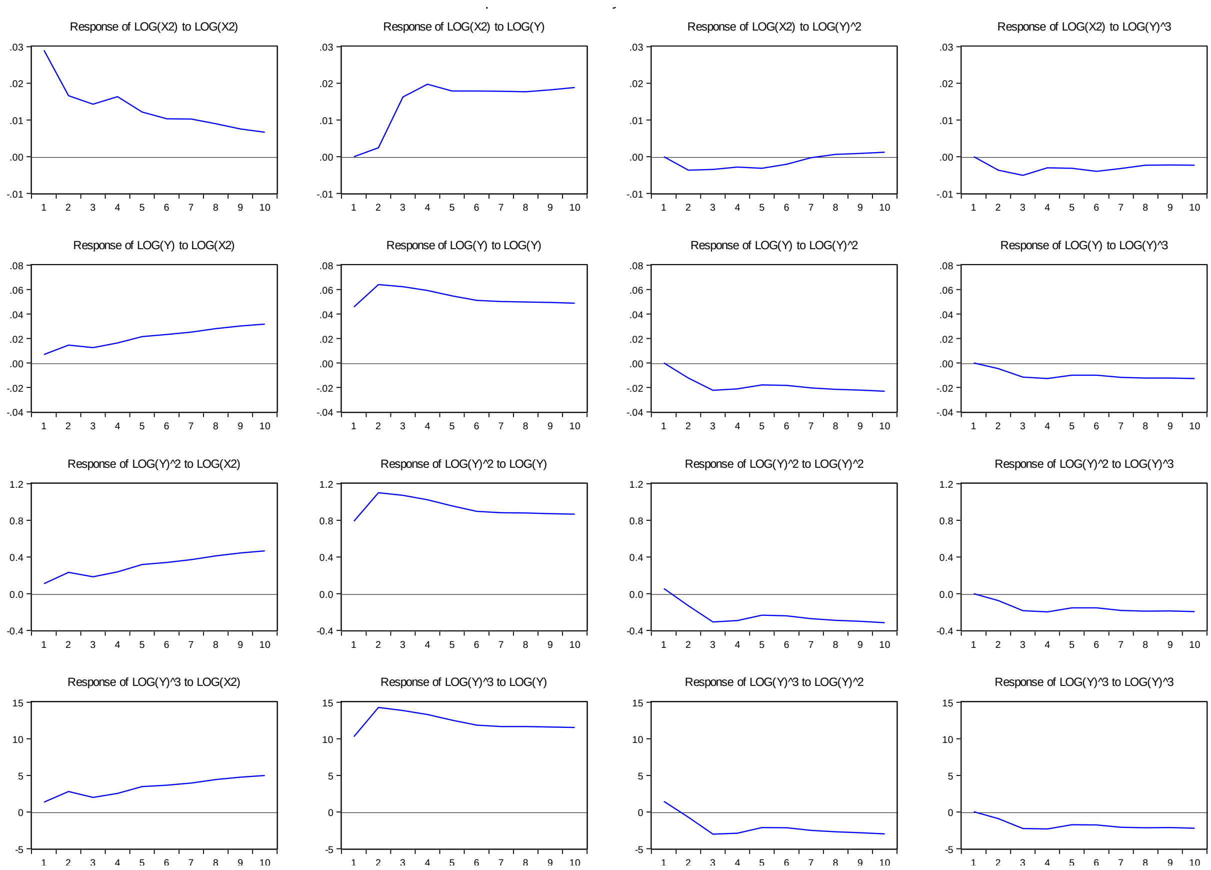

Figure 19: Impulse response function

Johansen cointegration test confirmed that there is at least one cointegrating equation in Trace statistic and Max Eigen statistic among log(x_1), log(y), log(y)^2 and log(y)^{3}which guarantee that there is long run association between global co_2 emission and global GDP per capita during 1970-2018 which is significant at 5% level.

Table 3: Cointegration test

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Probability**
None *	0.699398	83.81694	47.85613	0.0000
At most 1	0.286864	27.32446	29.79707	0.0939
At most 2	0.203405	11.43452	15.49471	0.1861
At most 3	0.015754	0.746334	3.841466	0.3876
		Max-Eigen Statistic		
None *	0.699398	56.49248	27.58434	0.0000
At most 1	0.286864	15.88993	21.13162	0.2314
At most 2	0.203405	10.68819	14.26460	0.1705
At most 3	0.015754	0.746334	3.841466	0.3876

Source-Calculated by author, * = rejection of the hypothesis at the 0.05 level, **=MacKinnon-Haug-Michelis (1999) p-values

Since there is cointegration then estimated VECM is given below.

Table 4: Vector Error Correction Model

Error Correction:	d(log(x_1))	d(log(y))	d(log(y)^2)	d(log(y)^3)
CointEq1	-0.067943	-0.088987	-1.269382	-13.71049
	[-2.89674]*	[-1.73607]*	[-1.42539]	[-1.17081]
d(log(x_1(-1))	0.302512	0.892879	14.61812	180.3276
	[1.64975]*	[2.22816]*	[2.09964]*	[1.96975]*
d(log(x_1(-2))	0.084990	0.944139	16.01045	205.3189
	[0.43516]	[2.21203]*	[2.15903]*	[2.10561]*
d(log(y(-1))	-29.03575	-32.57574	-541.5099	-6739.177
	[-2.62761]*	[-1.34896]	[-1.29066]	[-1.22154]
d(log(y(-2)	0.691807	-16.47022	-239.3987	-2644.034
	[0.08021]	[-0.87378]	[-0.73101]	[-0.61400]
d(log(y(-1))^2	3.523951	4.099877	67.60551	834.6017
	[2.65652]*	[1.41427]	[1.34228]	[1.26018]
d(log(y(-2))^2	-0.148302	2.071432	30.43196	340.2032
	[-0.14087]	[0.90035]	[0.76133]	[0.64726]
d(log(y(-1))^3	-0.141562	-0.170072	-2.784496	-34.12693
	[-2.67607]*	[-1.47116]	[-1.38635]	[-1.29217]
d(log(y(-2))^3	0.007854	-0.087842	-1.306558	-14.80667
	[0.18418]	[-0.94268]	[-0.80703]	[-0.69553]
C	0.022222	0.031198	0.514305	6.444895
	[4.26629]*	[2.74068]*	[2.60050]*	[2.47826]*
R-squared	0.327382	0.555604	0.482001	0.414874
F-statistic	1.946910	5.000974	3.722016	2.836137
Akaike AIC	-4.872197	-3.308639	2.401314	7.554062
Schwarz SC	-4.474666	-2.911108	2.798845	7.951593

Source-Calculated by author, *=significant at 5% level.

Estimated VECM states that the relations between dlog(x_1) and dlog(y (-1)) and dlog(x_1) and dlog(y(-1))^3 are negative but the relation between dlog(x_1) and dlog(y(-1))^2 is positive.

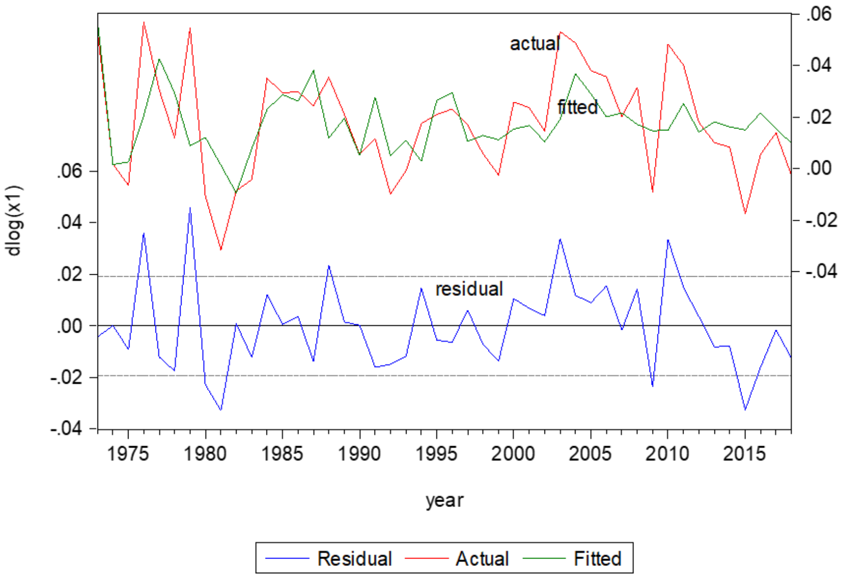

Figure 20: Change of log CO_2

The estimated dlog(x_1) has been moving towards equilibrium as found in the Vector Error Correction Model which is shown in Figure 20.

The cointegrating equation is estimated below.

$$Z_{t-1}=-0.0679\log(x_1(-1)) + 80.529\log(y(-1)) - 9.0945\log(y(-1))^2 + 0.3392\log(y(-1))^3 - 238.712$$
$$(-2.89)^* \quad (10.16)^* \quad (-9.94)^* \quad (9.08)^*$$

Since the coefficient of error term is negative and its t value is significant at 5% level and other t values of the coefficients are significant, then the cointegrating equation is significant and tends to equilibrium adjusting error by 6.79% per year. It indicates that there is long run causality to global CO_2 emission from the square and cube of global GDP per capita from 1970-2018.The following cointegrating graph also signify the relation.

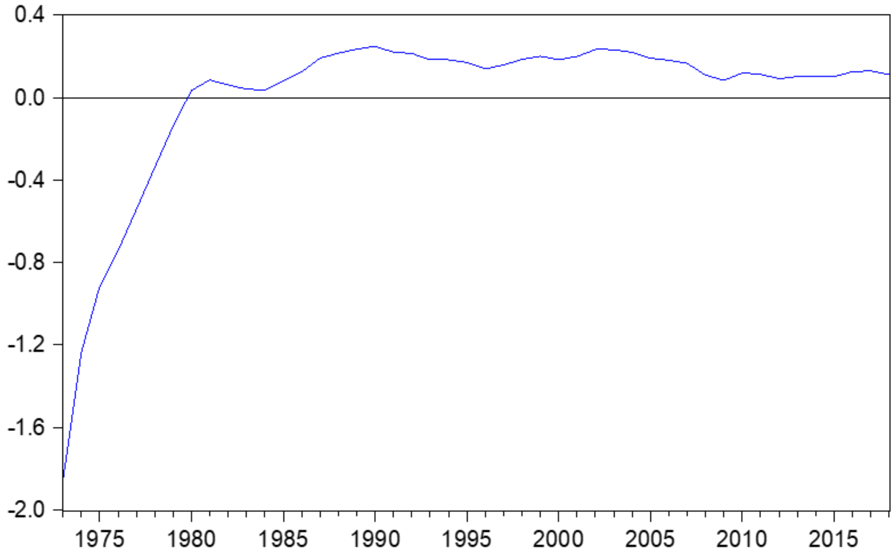

Figure 21: Cointegrating graph

The Vector Error Correction Model of CO_2 emission is stable and nonstationary because it has unit root and all roots lie inside or on the unit circle which is plotted below.

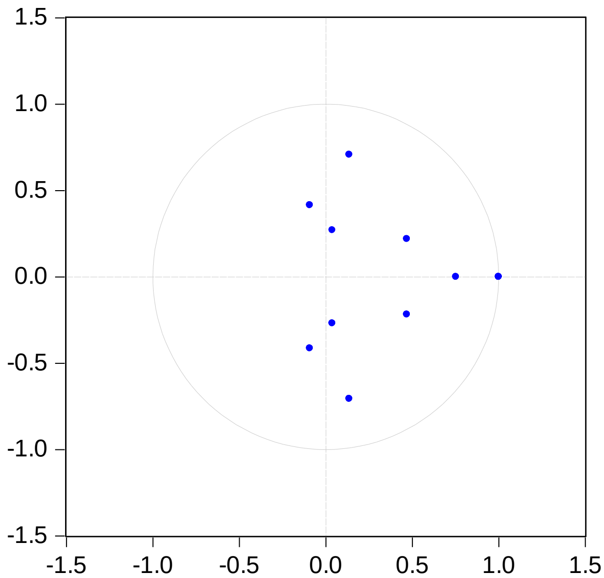

Figure 22: Unit circle

The second, third and fourth figures of the first row of the impulse response functions (measured by Response to Cholesky One Standard Deviation innovations) in Figure 23 represented that responses of global co_2 emission to global GDP per capita, GDP per capita square and GDP per capita cube have been moving towards equilibrium which support the long run causality.

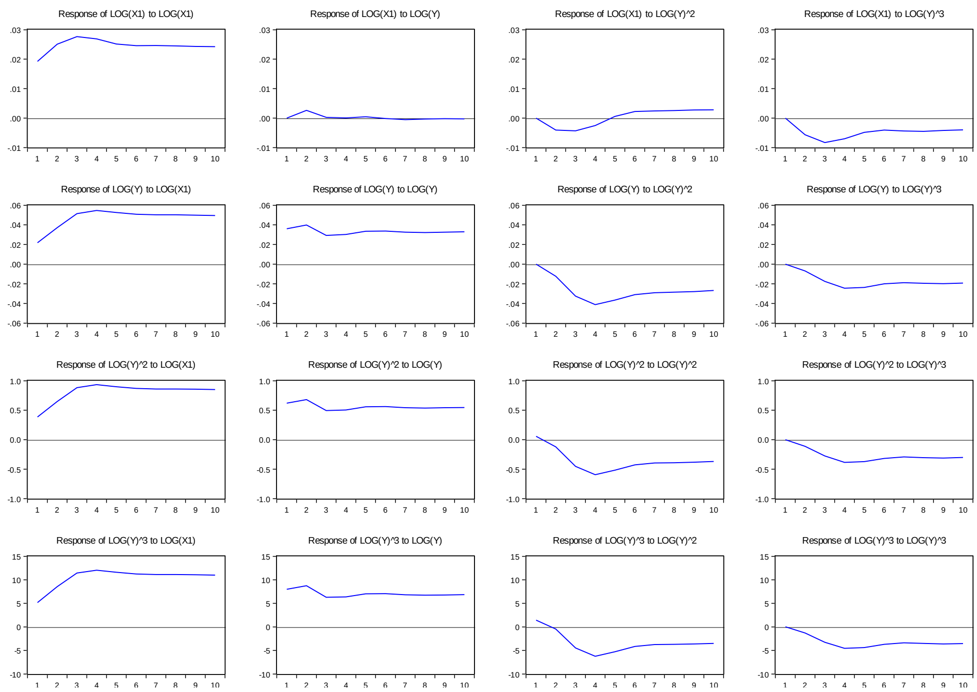

Figure 23: Impulse response function

5. POLICY CONSIDERATIONS

Lowering CH_4 is an alternative to atmospheric CO_2 removal which looks to be necessary for the Paris climate goals. To achieve the target of Paris Climate Change Agreement, U.N. Environment formulated a framework of guiding principles which focussed on cutting methane emissions from natural gas assets. The main objectives of the guiding principles are to [i] continually reduce methane emissions, [ii]advance strong performance across gas value chain, [iii] improve accuracy of methane emissions data, [iv] advocate sound policy and regulations on methane emissions, [v] increase transparency by providing information in external reports.

During the 2019 U. N. Climate Action Sumit, U. N. Environment and the Climate and Clean Air Coalition are looking to set up action on global alliance to cut methane for oil and gas sector which target at least 45% reduction of methane by 2025 and to cut 60-75% by 2030 or to a near zero methane intensity target. Even, the European Bank for Reconstruction and Development, the Environmental Défense Fund and the Oil and Gas Climate Initiative target to cut methane emissions by 75%. The Shared Socio-Economic Pathway 1 scenario allows for a low level of SLCPs by 2100 while CCPs must be zero or negative.

The studies of Van Dingenen et al (2018) estimated that unabated global anthropogenic CH_4 emissions would increase by 35% to 100% within 2050 in the pessimistic scenario or it would rise from $330TgCH_4\ yr^{-1}$ in 2010 to 450-650 Tg $CH_4\ yr^{-1}$ by 2050. But the optimistic scenario which targets to reach Paris Agreement goals projected 50% reduction of CH_4 emission amounting to 180-220 $TgCH_4\ yr^{-1}$ by 2050. By submitting a project report on behalf of UNECE,Haugland(2019) emphasised that [i] there are uncertainties of methane emission from oil and gas operation where quantification is difficult where Paris Agreement rulebook calls for enhanced national MRV efforts, [ii]enhanced methane emission reductions efforts can emphasise countries' efforts to meet Paris Agreement Targets.

India's CH_4 emission is 20% of all GHG emissions. The University of Bristol has studied that India's methane emission from 2010-2015 has been a little change from the bottom up reporting. The top down atmospheric observations indicated that total annual CH_4 emission from India was 22.0Tg per year which is equivalent to 24 million ton. But bottom up approach may able to find the sources of emissions which are very effective in formulating policies. India can implement three measures at no cost: efficient use of fertiliser, adaption of zero tillage and management of water used in rice irrigation. Even mitigation measures can be implemented in livestock sources.

Miller and Michalak(2019) estimated that the methane emission from China rose by 1.1±0.4TgCH_4yr from 2010 to 2015 culminating in total anthropogenic and natural emissions of 61.5±2.7TgCH_4 in 2015.Coal sector contributes the highest share of 33%.Chinese 12th five year plan specified that coal mine methane utilisation should have been 8.4 billion cubic meter or 5.6TgCH_4 by 2015 which will be 13.2TgCH_4 by 2020.US Environment Protection Agency identified three broad barriers that China would need to overcome to meet its coal mines methane targets which are insufficient infrastructure, inadequate technology and poorly designed policies to reach coal mine methane utilisation targets.

Chinese methane emission rose by 1.1 Tera gram each year from 2010 to 2015 resulting 50% higher level of annual CH_4 emission which is comparable to Russia or Brazil Ministry of Ecology and Environment organised methane forum where Tsinghua University and Environmental Défense Fund launched methane emission reduction policies to reach the target of climate policy of 2030.Chinese 50% methane emission streaming from energy activity(oil, gas,& coal).China has opportunity to reduce fossil fuel methane emission. China will launch Methane SAT satellite in 2021 to identify ,measure and verify fossil fuel methane emission et al(2019)studied that China's non-CO_2 GHG emissions from all sources contribute one third of total CO_2 GHG by 2050.It has projected to reduce non-CO_2 GHG by 30% within 2030.The combined mitigation measures can reduce from peak level of 2020 and planned to reduce 870Mt CO_2e by mitigation measures and by implementing current cost -effective non-CO_2 GHG mitigation measures. In coal mining 70% reduction is possible in mitigation of CH_4,waste and waste water contribute 20% reduction of emission by 2050.All are cost effective policies which follow the Paris Agreement Framework where mitigation of methane in Agricultural sector may be the greatest challenge.

EPA proposed cost saving measure which would save $97 to $125 million in oil and natural gas industry during 2019-2025.A recent study published in Science found that the US oil and gas industry emits 13 million tonnes of methane from its operations each year which is 60% more than estimated by EPA. Some policies at state level are as follows: In 2014, Colorado found and fixed methane leaks and installed technology to limit or prevent emissions. During 2017, it found that methane leaks fell by 52%. Massachusetts replaced old technologies and fixed methane leaks. California has adopted a novel approach which detected methane leaks from natural pipe lines. Texas and New Mexico considered adopting regulations to cost effective control flaring, venting, and leaks by requiring gas capture at oil well and by preventing them and seeks to promote new technology.

EPA has developed a number of voluntary programme as part of the Climate Change Action Plan to overcome market barriers and encourage cost effective methane recovery project.In US,total methane emission is projected at 183.7MMTCE by EPA in 2020 in which EPA launched five voluntarily projects to reduce CH4.,i.e.[i] AgSTAR program,[ii]Coalbed Methane Outreach Programme,[iii]Landfill methane outreach programme,[iv] Natural gas STAR programme,[v] Ruminant Livestock Efficiency programme.

According to EPA 2010 estimate, US methane reduction was possible to 34.8MMTCE(6.1Tg) using the cost market price of $20/TCE for abated methane, then US reduction could reach 50.3MMTCE(8.8Tg) in 2010 which will reach at 47.4 MMTCE in 2020 at the same cost level.(USEPA,1999).

Olczak and Piebalgs (2019) explained that methane emission accounted for 11% of total EU-28 GHG emission in 2016.It is declining 37% since 1990 to 457 million-ton co_2eq in 2016 mainly due to reduction in coal mining and anaerobic waste. Contribution of EU to global methane emission declined from 11% in 1990 to 6.4% in 2012 and forecasted to stabilise around 3-5% in 2030-2050.Currently agriculture is the main source of methane emission(237 Mt co_2 eq) followed by waste management(124Mt co_2eq) and energy(85Mtco_2eq).European Commission strategy paper in November 1996 for reducing methane emission are as follows. 1]In agriculture sector, commission suggested measures in two areas: [a]animal manure management and [b]enteric fermentation. Implementation policy consists of two steps,[i] the launch of program at national, regional and local levels,[ii]introduction of an obligation to install such recovery and use systems at the EU level.[2] In waste sector, proposal include adaption of EU legislation requiring the installation of methane recovery and use system at new and existing landfills. Commission proposed the use of economic incentives to promote recycle products.[3] In energy sector, EU recommended the best available technology for coal mines with 10-years of life span. In Agriculture, gas industry is solving the problem by developing biomethane for injection in its grid. Gas companies have been allowing significant incentives to prevent methane emission. Council attempted gradual reduction of biodegradable municipal waste filled up to 35% by 2016 and by 2020.EU can not meet its 2030 and 2050 targets nor ensure the success of the Paris agreements without EU methane legislation which will be boon for EU geopolitical outlook as its global market position.

IPCC Special Report on global warming of 1.5°C assured deep reductions in methane emission and black carbon by 35% or more within 2050 relative to 2010.The report also emphasised that 37% methane cut is necessary within 2030 to reach the target of warming below 1.5°C.

6.CONCLUSION

The paper concludes that global methane emission has been increasing at the rate of 1.06% per year significantly during 1970-2018 in comparison with 1.85% per year in global CO_2 emission. Actually, global methane emission is cubic in nature whereas CO_2 emission is quadratic. The methane emission contains four upward structural breaks as against five upward structural breaks of CO_2 emission. Both of them have significant cyclical trends of inverse S type in H.P. Filter model. In ARIMA (1,1,1) forecast model for 2050, global methane is stable and nonstationary but global CO_2 emission is stable and stationary showing convergent patterns. Both methane and CO_2 emissions have been absolutely decoupled from GDP per capita square and relatively decoupled from GDP per capita cube during 1970-2018 significantly which indicate that global methane and CO_2 emission follow Environment Kuznets Curve hypothesis. Global methane emission is cointegrated with GDP per capita having one cointegrating equation which tends to the equilibrium and CO_2 emission has two cointegrating equations which also move to equilibrium significantly, i.e. both methane and CO_2 emissions have long run causalities from GDP per capita from 1970 to 2018.

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