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The Effect of Organic Farms on Global Greenhouse Gas Emissions

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1. Introduction

The emission of greenhouse gases (GHGs) is a great concern for mankind as it believed that when GHGs such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), trap energy from the sun, they contribute to global warming. Even though greenhouse gases occur naturally in the atmosphere, there are noteworthy man-made contributions through agricultural and industrial production. Agricultural land itself contributes to 12% of global GHG emissions while emissions from all sectors related to agricultural production contribute to an estimated 25-30% of all GHG emissions (International Trade Centre, 2007). The Kyoto Protocol was established in Kyoto, Japan in December, 1997 as an amendment to the United Nations Framework Convention on Climate Change (UNFCCC) to regulate global GHG emissions. It remains the most comprehensive international agreement to date through the setting of target reductions by industrialized nations in North America, Europe, Asia and Australia, commonly known as "Annex I" countries, shown in Table A-1 of the Appendix.

The emissions of methane, projected to have approximately 20 times the global warming potential of carbon dioxide in trapping heat in the atmosphere (Morgenstern, 1991; Shih et al., 2006; International Trade Centre, 2007; EPA, 2011a) are caused by enteric fermentation and manure management, both of which are strongly correlated with livestock numbers (Vermont & De Cara, 2010), in addition to rice cultivation (McCarl & Schneider, 2000; Nalley et al., 2011). Enteric fermentation is a digestive process where microbes in ruminant animals such as cows, goat and sheep break down food, producing methane as a byproduct. Anaerobic decomposition (without oxygen) of organic matter in livestock manure leads to methane emissions. The U.S. Environmental Protection Agency's website also mentions natural sources of methane such as wetlands, oceans, wildfires as well as man-made sources including landfills (EPA, 2011a).

The emissions of nitrous oxide, projected to be far more potent at about 300 times the global warming potential of carbon dioxide (International Trade Centre, 2007; EPA, 2011b), stem from livestock management (nitrogen content from animal feeds), soil disturbance (both soil loss and degradation), fertilizer/ other chemical use and the burning of agricultural residues (Ruttan, 2002; Flugge & Schilizzi, 2005). The combustion of fossil fuels and microbes in tropical forests are also discussed as sources on the EPA's website (EPA, 2011b).

Carbon dioxide emissions, the least potent GHG in agriculture stem from fuel use (diesel and petrol) to operate heavy machinery and equipment (Flugge & Schilizzi, 2005) and soils

from changes in land use, including deforestation (International Trade Centre, 2007). However, the amount of CO_2 emissions from agriculture alone is trivial (McCarl & Schneider, 2000)[1] even though the total emission of this GHG is the largest compared to the five others (Grunewald & Martinez-Zarozos, 2009).

Table 1 shows the most recent GHG emissions by Annex I status and sector for 2005. These numbers are compiled using World Resources Institute's Climate Analysis Indicators Tool (CAIT, version 8.0) for 39 Annex I countries (including the European Union) and 146 non-Annex I countries. In furnished tables, Malta is erroneously labeled as an Annex I country. It is not certain whether Malta is also counted as an Annex I country in the tool that was used to generate this table. It became a European Union member (with Cyprus) after the protocol was signed but has not changed its non-Annex I status (UNFCCC, 2008).

Sources of GHG Emissions	All Countries	Annex I Countries	Non-Annex I Countries
1) Carbon Dioxide (CO_2) Emissions:			
Energy:			
Electricity & Heat	44.9%	45.1%	44.2%
Manufacturing & Construction	18.9%	14.5%	24.0%
Transportation	19.5%	24.7%	13.5%
Fugitive Emissions	0.7%	0.2%	1.2%
Industrial Processes	4.3%	1.9%	7.0%
2) Methane (CH_4) Emissions:			
Other Fuel Combustion	3.9%	2.4%	4.6%
Fugitive Emissions	24.2%	38.7%	19.5%
Industrial Processes	0.1%	0.3%	0.0%
Agriculture	51.4%	36.6%	57.7%
Waste	20.4%	22.1%	18.2%
3) Nitrous Oxide (N_2O) Emissions:			
Other Fuel Combustion	7.1%	13.6%	4.3%
Industrial Processes	4.8%	9.3%	3.2%
Agriculture	84.7%	72.4%	89.5%
Waste	3.4%	4.7%	3.0%

Table 1. Sources of 2005 GHG Emissions by Sector

While data is available for methane and nitrous oxide emissions solely in agriculture, there is no comparable carbon dioxide emission data specific to the industry. As expected, agricultural CH_4 and N_2O emissions contribute more for non-Annex I countries, those that

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[1] The EPA's estimate of agricultural CO_2 emissions for the United States in 1996 was less than 1% of the U.S. total emissions of this GHG.

are not subject to the country-specific reductions outlined in the Kyoto Protocol. The pattern is not clear for agricultural CO_2 emissions which may appear in several of the existing categories shown in Table 1. In addition, the total CO_2 emissions exclude the supplementary data on CO_2 emissions from land-use change and forestry which is only available for 14% of the countries (4 Annex I countries and 22 non-Annex I countries). As a result, I do not analyze agricultural carbon dioxide emissions in this chapter and focus on just agricultural methane and nitrous oxide emissions.

Figure 1 and Figure 2 show agricultural emissions of both methane and nitrous oxide (the left panels are for the total levels and the right panels are for the per capita levels) averaged across Annex I and non-Annex I countries. They are measured in thousand metric tons CO_2 equivalent (MtCO$_2$e) and MtCO$_2$e respectively. This data is compiled from World Bank's World Development Indicators (WDI) from 1990, available every five years until 2005.
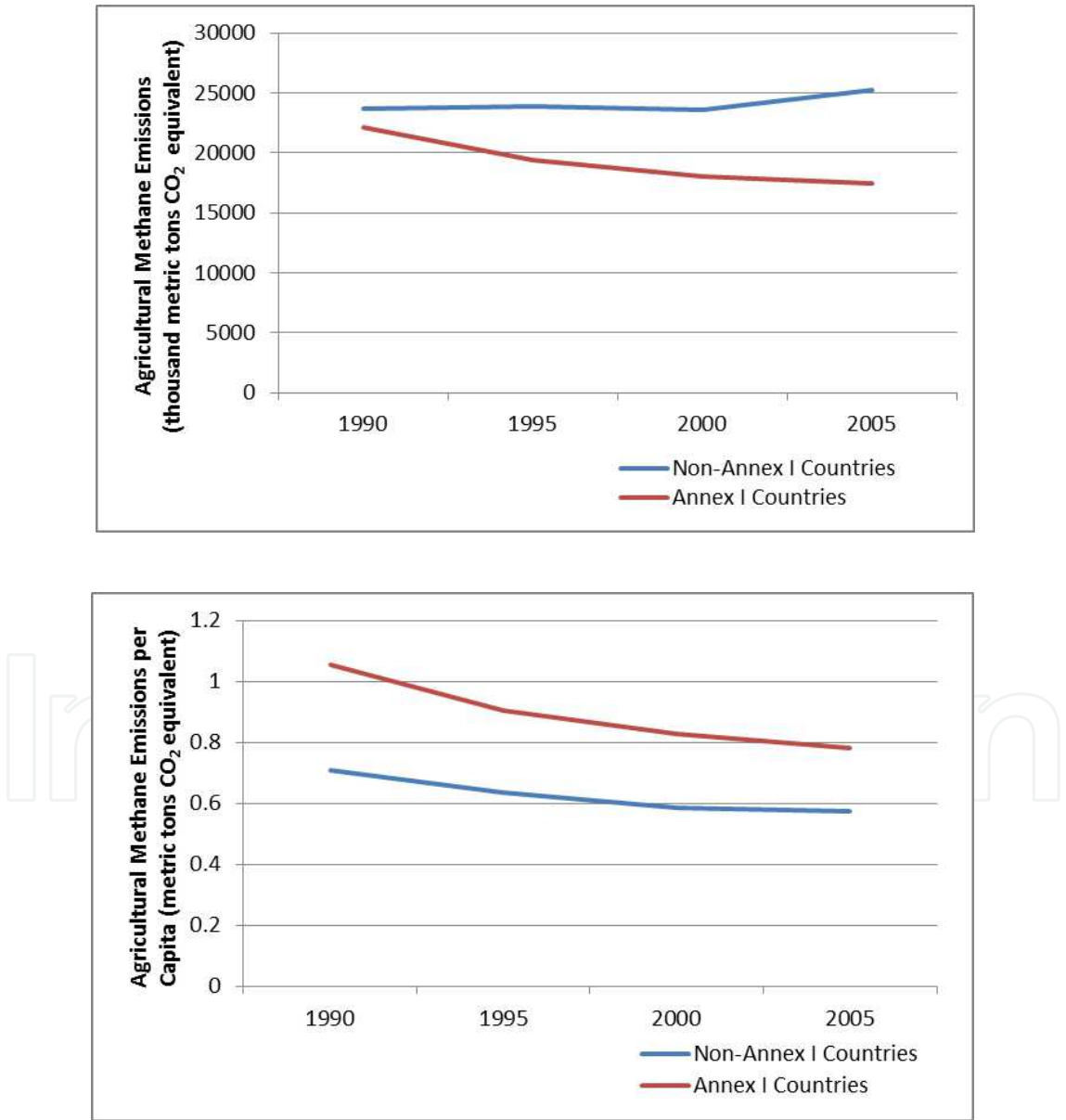

Fig. 1. (a) Agricultural CH_4 Emissions and (b) Agricultural CH_4 Emissions per Capita
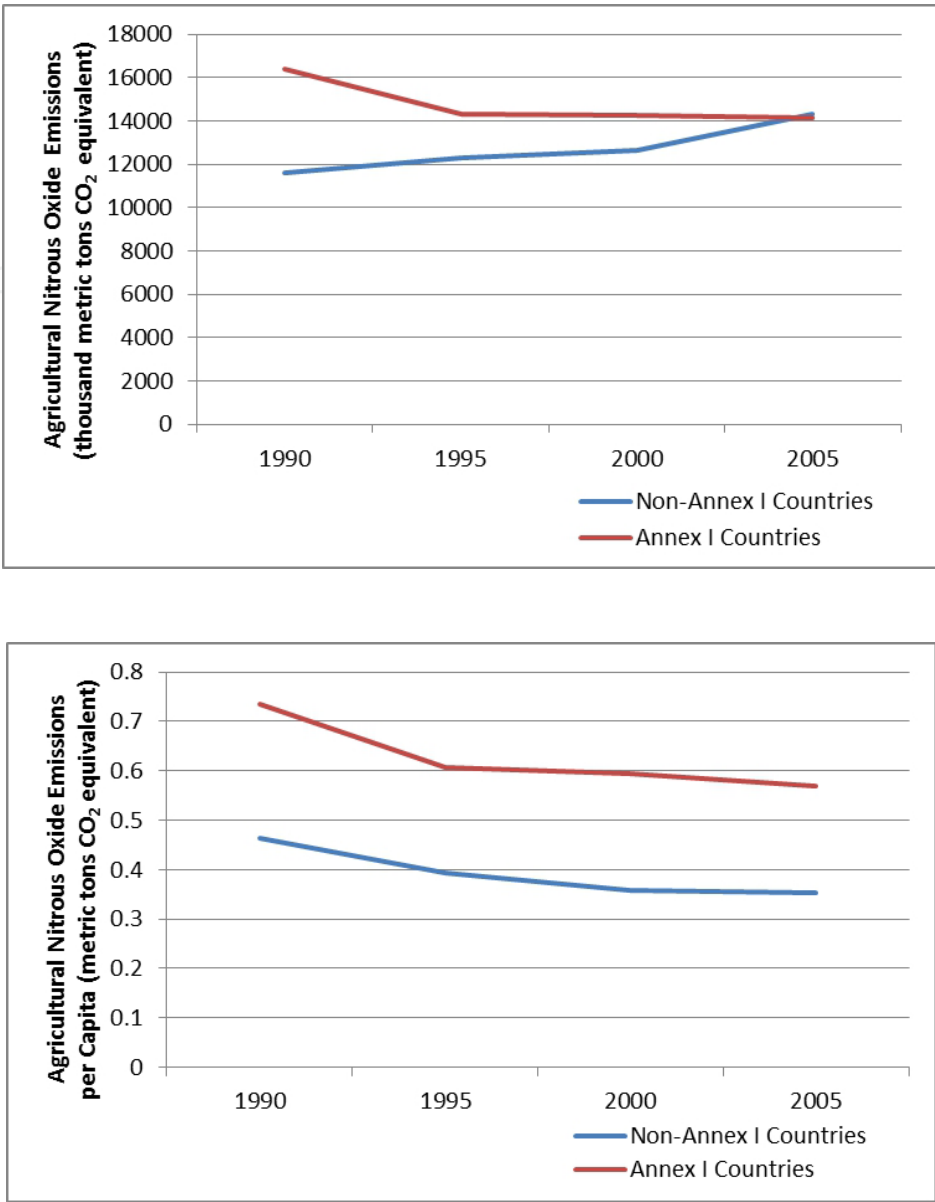
Fig. 2. (a) Agricultural N_2O Emissions and (b) Agricultural N_2O Emissions per Capita

Without controlling for population, both agricultural CH_4 and N_2O emissions increased for just non-Annex I countries. This is not surprising given that one of the world's most heavily populated countries with substantial emissions, China, is in this category. Since the signing of the Kyoto Protocol, Annex I countries have been experiencing declines in the total levels. On a per capita basis, both GHG emissions declined at about the same rate after 1995 even though non-Annex I countries are not subject to target reductions. Roca et al. (2001) argue that the environmental pressure to assimilate is an important consideration for countries.

In recent years, there has been a shift toward organic farm production in Western societies, primarily for promoting better health and for implementing sustainable business practices (Ruiz de Maya et al., 2011). It has been argued that organic farms provide an unintended side benefit of reducing the greenhouse gas emissions (International Trade Centre, 2007). Organic products are defined as, "goods that respect the environment and that are manufactured

without the use of synthetic pesticides, herbicides, chemical fertilizers, growth hormones, antibiotics or gene manipulation" (Chen, 2009). As the Kyoto Protocol is not aimed at reducing the emissions of developing countries, I argue that organic farming practices may have accounted for the reduction of GHGs in only Annex I countries. These are also countries that can afford organic production as such farms tend to operate on a smaller scale and may not employ the least-cost production techniques due to the tradeoffs between quality and quantity. Furthermore, agriculture in developing countries tends to be large-scale and more likely non-organic since it serves as the primary export industry that has the competitive edge in low-cost production in the world. With frequent use of fertilizers, pesticides and herbicides to maximize agricultural output, such practices are predicted to have increased the greenhouse gas emissions in non-Annex I countries relative to Annex I countries.

This research makes a contribution to the literature that explores a direct link between organic farming practices and the emissions of nitrous oxide and methane across countries. The chapter continues as follows. After a cross-disciplinary and detailed literature review in various areas, I provide the economic model to be estimated. The chapter concludes after a discussion of the empirical results and conclusions.

2. Review of the literature

Below, a review of the literature is provided in three key areas: (1) the Kyoto Protocol and its effectiveness; (2) previous models of GHG emissions using the Environmental Kuznets Curve (EKC) model and (3) the mitigating effects of organic farms on GHG emissions.

2.1 The Kyoto protocol and Its pros and cons

The effectiveness of the Kyoto Protocol has continued to be contemplated by researchers across disciplines. The international agreement calls for the reduction in combined emissions of six of the main greenhouse gases, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride (McCarl & Schneider, 2000; UNFCCC, 2008). There are specific emission targets listed for each of the 38 industrialized nations plus the European Union ("Annex I countries"), outlined in a section called "Annex B" in the protocol. These reduction targets in GHG emissions which are listed in Table A-1 of the Appendix will account for a 5.3 percent collective reduction of the 1990 emission levels by the first commitment period of 2008-2012 (Sathiendrakumar, 2003; Finus, 2008; Grunewald & Martinez-Zarzoso, 2009). Belarus and Turkey were not parties to the UNFCCC and so they are Annex I countries that have no target reductions. The United States remains the sole Annex I country that has not ratified the Kyoto Protocol despite being an integral member (Kumazawa & Callaghan, 2010). Most countries use the 1990 baseline emissions but Japan and the former members of the Soviet Union have argued for flexible baselines.

While setting rigid country-specific target reductions, the protocol allows for flexibility in meeting these targets through emissions trading, clean development mechanism (CDM) or joint implementation between countries as long as eligibility requirements are met (Rollings-Magnusson & Magnusson, 2000; McKibbon & Wilcoxen, 2002; Finus, 2008). The Kyoto Protocol recognizes the uniqueness of the agricultural industry in the emissions reduction process. In another section of the protocol called "Annex A," the agricultural sources of emissions listed include enteric fermentation, manure management and deforestation while sinks to offset the emissions include afforestation and reforestation (McCarl & Schneider, 2000; UNFCCC, 2008).

One of the shortcomings of the Kyoto Protocol is that it did not go into force until 2005, eight years after it was adopted in 1997. It was only after Russia's ratification that 55 countries which had emitted at least 55% of the greenhouse gases had ratified the protocol (Finus, 2008; Grunewald & Martinez-Zarzoso, 2009). The UNFCCC's principle of "common but differentiated responsibilities" means that the responsibilities for reduction efforts fall disproportionately on the industrialized nations because they had contributed more toward GHG emissions than others. Another criticism of the protocol is that it does not address each GHG and sector individually as separate but linked agreements (Barrett, 2008).

The most problematic areas in the international agreement have been compliance and participation (Bohringer, 2003). The United States is still the only Annex I country which has yet to ratify the protocol and its target reduction of 7 percent is not binding even though a substantial 25% of the world's emissions originate in the US (Sathiendrakumar, 2003). The cost of compliance is not cheap and is estimated to be as much as 2.6 percent of the US GDP (Jaffe et al., 1995), a costly price to pay for a country which is in a chronic trade deficit. Australia and Russia initially followed in the footsteps of the United States but they ratified the protocol in 2007 and 2004, respectively, with provisions.

2.2 Previous research using the EKC Model

Agricultural production has long been considered to be an essential condition for a country's overall economic growth (Ruttan, 2002) in the development phase. However, few paid attention to how this growth was achieved until recent decades when it became evident from scientific data that global warming should be a cause for major concern. As countries experience economic development, they typically transition away from traditional and labor-intensive small-scale farming toward capital-intensive and even chemically-intensive large-scale farming (Ruttan, 2002; Goodstein, 2008). The economies of scale from the latter farms contribute to lower prices, creating comparative advantages in the global market. It is only when countries become richer that people can afford to demand more control over pollution and environmental degradation (Goodstein, 2008; Dasgupta et al., 2002), a reason why more regulations for pollutants exist in the environmentally-conscious and affluent Western societies.

The Environmental Kuznets Curve (EKC) hypothesis states that there is an inverted U-shaped relationship between economic development and environmental damages. Figure 3 shows that until a country reaches a turning point, there is continuous environmental degradation, at which point the country reverses the path and starts to experience an environmental improvement (Grossman and Krueger, 1995).

Past empirical research that uses the EKC model analyzes the impact of carbon dioxide (Shafik, 1994; Schmalensee et al., 1998; Dijkgraaf & Vollebergh, 2005; Aldy, 2007; Grunewald & Martinez-Zarzoso, 2009; Kumazawa & Callaghan, 2010) and common air pollutants including sulfur dioxide (Grossman & Krueger, 1995; Roca et al., 2001; Harbaugh et al., 2002). One of the few studies which investigated the EKC model for nitrous oxide and methane is the research by Roca et al. (2001).

Empirically, the Environmental Kuznets Curve is shown by the effect of the GDP per capita (Y) and GDP per capita squared on the emissions per capita (E), all in logged form for a panel data regression analysis. The square of the logged income per capita is included to allow for nonlinearity in the parameter. The log transformation of the variables Y and E
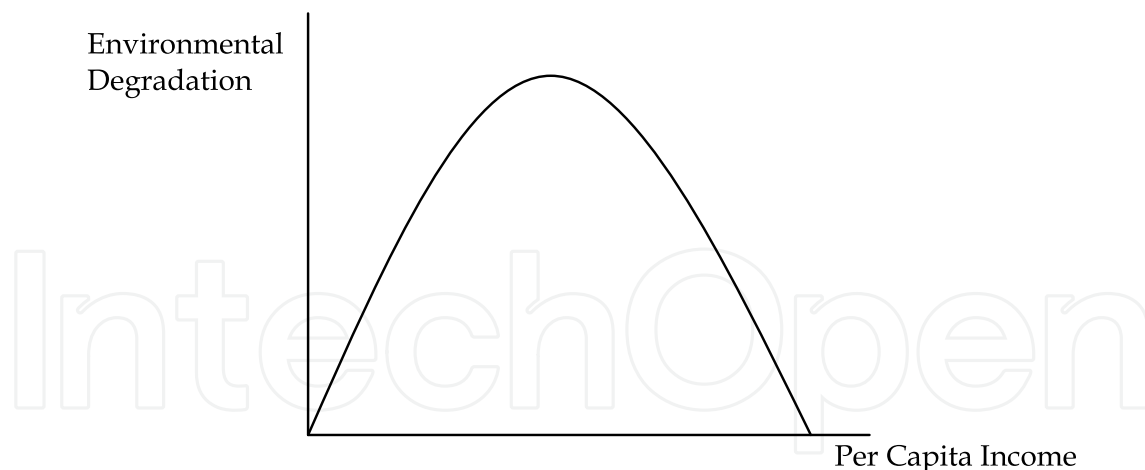
Fig. 3. Environmental Kuznets Curve (EKC)

the conventional EKC model where the subscript i denotes country and the subscript t denotes year in a cross-sectional time series data set. τ stands for a matrix of year dummy variables that control for the time trend. The time-invariant heterogeneity (α_i) and the idiosyncratic time-varying error term (ε_{it}) make up the composite error term. Past research indicates that political institutions play a role (Congleton, 1992). This may be an example of the unobservable heterogeneity, in addition to country land mass and country temperature/climate which stay relatively constant over time. The betas are the regression coefficients, β_0 the intercept and β_1 and β_2 the slopes.

$$\ln(E)_{it} = \beta_0 + \beta_1 \ln(Y_{it}) + \beta_2 [\ln(Y_{it})^2] + \tau_t + \alpha_i + \varepsilon_{it} \qquad (1)$$

Grossman & Krueger (1995) and Schmalensee et al. (1998) find empirical evidence for the EKC model that developed countries experience the "inverted-U" EKC in their environmental emissions. Grossman and Krueger (1995) find the turning point to be before a country reaches a per capita income of $8,000. Notable exceptions are Shafik (1994) and Dijkgraaf & Vollebergh (2005) who do not find the same shape for their EKC. The role of industrial production has been incorporated in recent studies of CO_2 emissions. Aldy (2007) finds that emission-intensive industrial production grows faster when there are fewer regulations. Kumazawa & Callaghan (2010) estimate an "augmented EKC model" (the conventional EKC model with additional independent variables) controlling for industrial production and test for structural breaks in the pre- and post- agreement years of the Kyoto Protocol. The authors find that carbon dioxide emissions, especially for industrialized nations (Annex I countries) show a decline since the signing. The model used in this chapter will be a variation of this augmented EKC model, specifically for agricultural production. Roca et al. (2001) find that only sulfur dioxide emissions exhibits the classic inverted U-shape of the EKC for Spain. Both methane and nitrous oxide emissions have increased but not decreased with economic growth for the country.

2.3 The mitigating effects of GHG emissions through organic farming

Mitigating the effects of non-CO_2 greenhouse gases is not an entire new idea in agriculture. Collecting methane from livestock manure through anaerobic digesters and using the captured gas, known as "biogas" to generate electricity reduces overall GHG emissions on farms (Shih et al., 2006; Lazarus et al., 2011). McCarl & Schneider (2000) advocate the

reduction in the use of nitrogen fertilizers and animal feed with nitrogen content to reduce nitrous oxide emissions.

Mitigating the effects of N_2O and CH_4 through organic farm practices follow along similar lines. The only study to date on this topic is the one conducted by the International Trade Centre (2007). In it, the following arguments are made. Organic farms engage in ley-farming where the field is left fallow after a few years of growing cash crops. The grasses and other plants grown on these fields during the fallow phase increase the nitrogen content of soils naturally without relying on nitrogen fertilizers which is seen as a direct cause of nitrous oxide emissions. In 2005 alone, global consumption of nitrogen fertilizers amounted to a staggering 91 million tons (International Trade Centre, 2007). Manure from livestock can also be recycled as a natural fertilizer, instead of being treated as waste material which, if not treated properly also contributes to emissions.

Organic agriculture also reduces the number of livestock per hectare, which is directly proportional to the emissions of both nitrous oxide and methane. The concentration of nitrous oxide can be more manageable with fewer livestock. In addition, the effects of methane from enteric fermentation and anaerobic decomposition can be reduced by having fewer livestock. Anaerobic digestion of manure and the production of biogas, while not a completely organic production method, have been at the forefront especially on organic farms. These are methods used on organic farms that directly reduce both methane and nitrous oxide emissions in addition to providing chemical and fertilizer-free products for the health-conscious consumers.

3. Data

Even though the idea of investigating the relationship between greenhouse gases and agriculture specifically to do with organic farming practices is very simple, compiling the data set proved to be extremely difficult. While carbon dioxide emission data is readily available for most countries annually over several decades, the same cannot be said of nitrous oxide and methane emission data.

At first glance, the World Resources Institute's Climate Analysis Indicators Tool (CAIT, version 8.0) seems to provide the most comprehensive data for 185 countries in 1990, 1995, 2000 and 2005 for both GHGs. However, upon careful analysis, there seem to be errors in reporting. Sometimes, countries that have small but positive total emissions per capita of either N_2O or CH_4 (in units of $MtCO_2e$) have zero emissions due to rounding to only one decimal place (for instance, 0.04 rounded to one decimal place becomes 0.0). This makes the distinction between a very small number and an actual zero to be indistinguishable. The agricultural emissions of both of these gases also suffer from the same problem.

The World Bank's World Development Indicators (WDI) also reports agricultural emissions of both N_2O and CH_4 for 133 countries (excluding Hong Kong, Taiwan and other island nations) in the same four years. These numbers do not always match those from the World Resources Institute but are measured in thousands of $MtCO_2e$, with several decimal places. I obtain these numbers so that the emissions per capita can be calculated with ease by multiplying the emissions by a thousand and dividing by the population. The population, real GDP per capita (in 2000 $US) and fertilizer consumption information are also extracted from WDI for the same countries that have the two GHG emission data. The size of the

arable land in hectares is obtained for all countries using FAOSTAT, a data extraction tool for the Food and Agriculture Organization of the United Nations.

There are further problems in obtaining additional control variables for the estimation of the augmented EKC model for CH_4 and N_2O emissions. The most problematic is the key information on organic farming. Both the WDI and FAOSTAT have variables on organic land relative to agricultural or arable land but there are more missing values than observations for most countries until the late 2000s. Euromonitor International's World Environment Factbook (2008) has comprehensive data on the number of organic farms, average size of organic farms (in hectares), land used in organic farming (in hectares) and the share of organic land relative to total land for 2001 to 2007 for 71 countries of the world. Even though the use of these variables would reduce the sample size to less than 50%, as there are no alternatives, I do so without much hesitation.

I obtained data on consumption of pesticides (thousand tons), herbicides (thousand tons), livestock numbers (in 1000 heads) and production of cereals (all grains including rice in thousand tons) from the World Environment Factbook (2008) as well. Each of these variables can also be obtained using FAOSTAT in finer detail (for example, gross production value of rice and consumption of nitrogen from fertilizers) but again, there were substantial missing values for most countries which made the data unusable. Table A-3 in the Appendix outlines all variables collected, the data sources and availability of countries and years.

The final sample of 55 countries for the augmented EKC model consists disproportionately of industrialized nations due to the availability of data. Annex I countries are overrepresented (there is 87% of them) while non-Annex I countries are underrepresented (there is only 14% of them). These countries make up approximately 60% of the world's agricultural emissions of methane and 50% of the world's agricultural emissions of nitrous oxide. China which emits 15% of the world's emission of agricultural methane and 22% of the world's agricultural nitrous oxide is excluded in the analysis because it does not have the key organic farming information. Japan, Philippines, Singapore and South Korea are excluded due to the same reason, for the lack of organic farm data.

4. Empirical estimation

Since the data for emissions of agricultural methane and nitrous oxide are available in 1990, 1995, 2000 and 2005, the country data is stacked for the four years in panel format, allowing for an unbalanced panel. In the conventional EKC model, a panel regression is run for the logged per capita emissions on logged per capita income and the squared logged per capita income, with three dummy variables for the years. This is done for each GHG separately for all 131 countries and then by Annex I status. A positive sign on ln (GDP per capita) and a negative sign on ln (GDP)^2 presence of an inverted U-shaped EKC. The results are presented in Table 2 and Table 3. The Hausman Specification Test is used to test between the fixed-effect model and the random-effect model, where α_i is randomly distributed.

The EKC model, augmented with organic farm practices and other sources of the GHGs, has some data constraints. The additional variables are collected for 2001 to 2007 and 2005 is the only where all variables are available at the same time. For livestock, pesticide, herbicide and cereal data, I approximate the 2000 data with 2001 data, as there is not enough data in the time series to be extrapolating the missing values reliably for each country. The resulting panel data is for two years, for a subset of 55 countries.

For agricultural emissions of CH_4, the conventional EKC model is augmented with arable land size, the number of organic farms and livestock, consumption of pesticides and production of cereals. These independent variables are chosen based on the literature. They are converted to logs so that elasticities are estimated. Methane stems from both enteric fermentation and anaerobic decomposition, manure management of livestock and rice cultivation. All variable, except the number of organic farms, are expected to increase methane emissions. The number of organic farms is expected to reduce methane emissions through organic practices used in agricultural production. The results are presented in Table 4.

For agricultural emissions of N_2O, the conventional EKC model is augmented with arable land size, the number of organic farms and livestock and consumption of fertilizers, pesticides and herbicides, all in logged form. These variables are also chosen based on the literature. Nitrous oxide stems from chemical usage on farms and livestock management. All variables, except the number of organic farms, are expected to increase nitrous oxide emissions. The results are presented in Table 5.

5. Results

The conventional EKC models for agricultural methane and nitrous oxide emissions are presented in Tables 2 and 3. A full list of countries used is provided in Table A-2 of the Appendix.

Variable	All Countries	Annex I Countries	Non-Annex I Countries
ln (GDP per capita)	0.411*	-2.114***	1.057***
	(0.219)	(0.582)	(0.277)
ln (GDP per capita)^2	-0.013	0.169***	-0.066***
	(0.015)	(0.035)	(0.020)
Dummy Variable for 1990	0.330***	0.670***	0.249***
	(0.025)	(0.049)	(0.027)
Dummy Variable for 1995	0.184***	0.454***	0.138***
	(0.024)	(0.049)	(0.026)
Dummy Variable for 2000	0.072***	0.185***	0.049**
	(0.021)	(0.036)	(0.024)
Constant	-3.360	4.110	-5.146
	(0.787)	(2.443)	(0.942)
R^2	0.410	0.682	0.360
Number of Observations	513	152	357
Number of Countries	131	38	92
Average Number of Years	3.9	4.0	3.9
Hausman Specification Test (χ^2)	16.52**	33.07***	30.25***

Notes: (1) Standard errors in parentheses below coefficients.

(2) Statistical significance at 1% (***) , 5% (**) and 10% (*).

Table 2. Conventional EKC Model for Agricultural Methane Emissions

In Table 2, the coefficients on ln (GDP per capita) and ln (GDP per Capita)^2 indicate that Annex I countries face an unexpected U-shaped EKC while non-Annex I countries face the expected inverted U-shaped EKC. However, the result for Annex I countries may be due to the relative short span of emission data which is only available every five years. Most developed countries would have already achieved economic growth by 1990. For Annex I countries, on average, a one percent increase in income per capita decreases per capita emissions of methane by 2 percent. For non-Annex I countries, on average, a one percent increase in income per capita raises emission per capita by 1 percent. All year dummy variables have positive and statistically significant coefficients. The Hausman Specification Tests across all three columns indicate that the fixed-effect model is the appropriate model which takes into consideration the time-invariant characteristics of each country.

In Table 3, the EKC has the expected inverted-U shape for non-Annex I countries and the unexpected U-shape for Annex I countries again. This time, the coefficient on ln (GDP per capita) is not statistically significant, meaning that income per capita has no effect on emissions per capita of nitrous oxide. The coefficient for non-Annex I countries is slightly higher compared to the previous table. All year dummy variables, while unreported in the table, have positive and statistically significant coefficients. The Hausman Specification Tests across all three columns indicate that the fixed-effect model is the appropriate model again.

Variable	All Countries	Annex I Countries	Non-Annex I Countries
ln (GDP per capita)	0.714***	-0.347	1.214***
	(0.223)	(0.516)	(0.304)
ln (GDP per capita)^2	-0.024	0.068**	-0.066***
	(0.016)	(0.031)	(0.022)
Dummy Variable for 1990	0.307***	0.564***	0.244***
	(0.025)	(0.043)	(0.030)
Dummy Variable for 1995	0.168***	0.355***	0.145***
	(0.025)	(0.044)	(0.029)
Dummy Variable for 2000	0.080***	0.166***	0.066**
	(0.021)	(0.032)	(0.026)
Constant	-5.381	-3.668	-6.705
	(0.801)	(2.164)	(1.033)
R^2	0.375	0.681	0.313
Number of Observations	513	152	357
Number of Countries	131	38	92
Average Number of Years	3.9	4.0	3.9
Hausman Specification Test (χ^2)	36.50***	53.31***	108.19***

Notes: (1) Standard errors in parentheses below coefficients.

(2) Statistical significance at 1% (***) , 5% (**) and 10% (*).

Table 3. Conventional EKC Model for Agricultural Nitrous Oxide Emissions

The augmented EKC model for methane is presented in Table 4. Compared to the conventional EKC model, the results are dissimilar for the different groups of countries due to the smaller cross-sections of countries and fewer years used. First, the inclusion of additional independent variables makes the EKC seemingly less robust, an observation made by Harbaugh et al. (2002) as both income variables are no longer statistically significant. For Annex I countries, livestock plays a significant role in increasing methane emissions. On average, a one percent increase in livestock numbers increases the agricultural methane emissions per capita by 0.8 percent, ceteris paribus. However, for non-Annex I countries, it is the consumption of fertilizers that matters. On average, a one percent increase in fertilizer consumption increases the agricultural methane emissions per capita by 0.3 percent, ceteris paribus. The production of cereal shows no significant impact on methane. This may be due to the fact that this variable measures the production of other grains, too.

Variable	All Countries	Annex I Countries	Non-Annex I Countries
ln (GDP per capita)	0.053 (0.382)	-0.083 (0.414)	0.122 (0.970)
ln (GDP per capita)^2	0.008 (0.024)	0.012 (0.027)	0.0002 (0.064)
ln (Arable Land in Hectares)	-0.155** (0.072)	-0.027 (0.083)	0.017 (0.138)
ln (Number of Organic Farms)	-0.004 (0.021)	0.055*** (0.019)	-0.051 (0.038)
ln (Number of Livestock)	0.405*** (0.072)	0.783*** (0.088)	0.171 (0.144)
ln (Consumption of Pesticides)	0.059 (0.050)	0.036 (0.044)	0.306*** (0.097)
ln (Production of Cereals)	-0.012 (0.058)	0.021 (0.054)	0.037 (0.107)
Dummy Variable for 2000	0.065*** (0.015)	0.062*** (0.017)	0.036 (0.042)
Constant	-6.404 (1.799)	-14.302 (3.063)	-8.003 (3.822)
R^2	0.545	0.901	0.505
Number of Observations	97	62	35
Number of Countries	54	33	21
Average Number of Years	1.8	1.9	1.7
Hausman Specification Test (χ^2)	6.27	40.41***	6.50

Notes: (1) Standard errors in parentheses below coefficients.

(2) Statistical significance at 1% (***) , 5% (**) and 10% (*).

Table 4. Augmented EKC Model for Agricultural Methane Emissions

The result that stands out is the effect of the number of organic farms for Annex I countries. It has an unexpected positive sign and is statistically significant. While not reported, other variables for organic farm production (average size of organic farms, land used in organic farming and the share of organic land relative to total land) also exhibit positive but smaller

effects on methane emissions. Perhaps, it signifies the shortcoming of what these variables actually measure. There is no distinction on whether the organic farms are dairy farms or not. If there are disproportionate shares of dairy farms among organic farms, it is entirely possible to expect the sign on the variable to be positive through enteric fermentation and anaerobic decomposition.

It is noteworthy that for all columns except Annex I countries, the Hausman Specification Test could not reject the random-effect model. A shortcoming of this model may be that the natural sources of methane such as the number of landfills and wetlands were not controlled for due to the lack of available data.

The augmented EKC model for nitrous oxide is presented in Table 5. Again, the results differ from those of the conventional EKC model. The income variables are not statistically significant except for the case where all countries are considered together and show the inverted-U shape.

Variable	All Countries	Annex I Countries	Non-Annex I Countries
ln (GDP per capita)	1.536***	0.444	-0.623
	(0.551)	(0.674)	(0.822)
ln (GDP per capita)^2	-0.086**	-0.016	0.072
	(0.038)	(0.042)	(0.059)
ln (Arable Land in Hectares)	0.233*	0.100	0.586***
	(0.131)	(0.126)	(0.145)
ln (Number of Organic Farms)	0.022	0.081**	-0.051
	(0.029)	(0.035)	(0.034)
ln (Number of Livestock)	0.213*	0.038	-0.045
	(0.123)	(0.160)	(0.150)
ln (Consumption of Pesticides)	0.367**	-0.181	1.045***
	(0.155)	(0.202)	(0.201)
ln (Consumption of Herbicides)	-0.250	0.122	-0.877**
	(0.153)	(0.180)	(0.238)
ln (Fertilizer Consumption)	0.155**	0.099	0.460***
	(0.061)	(0.062)	(0.108)
Dummy Variable for 2000	0.031	0.090***	0.004
	(0.026)	(0.026)	(0.058)
Constant	-16.996	-6.195	-13.755
	(3.384)	(5.110)	(4.946)
R^2	0.506	0.725	0.936
Number of Observations	94	60	34
Number of Countries	52	32	20
Average Number of Years	1.8	1.9	1.7
Hausman Specification Test (χ^2)	40.6***	53.18***	63.48***

Notes:　(1) Standard errors in parentheses below coefficients.

　　　　(2) Statistical significance at 1% (***) , 5% (**) and 10% (*).

Table 5. Augmented EKC Model for Agricultural Nitrous Oxide Emissions

Across all columns, the Hausman Specification Tests show the rejection of the random-effect model in favor of the fixed-effect model. Furthermore, the natural sources of N_2O are not controlled for in the regressions due to the lack of available data.

For Annex I countries, only the number of organic farms matter and it is again, statistically significant with the wrong sign. For non-Annex I countries, the use of chemicals in agricultural production increase N_2O emissions. On average, a one percent increase in pesticide consumption increases agricultural emissions of nitrous oxide per capita by one percent, all else equal. Similarly, a one percent increase in fertilizer consumption increases the same GHG emission per capita by 0.5 percent, all else equal. Curiously, the consumption of herbicides decreases emissions per capita. Perhaps, this is indicative of how the combination of chemicals used in agricultural production affects nitrous oxide emissions.

6. Conclusions

This chapter is one of the first kinds to investigate the Environmental Kuznets Curve hypothesis for nitrous oxide and methane, specifically in agriculture. Using a sample of 131 countries, the conventional EKC model shows the classic inverted-U EKC for non-Annex I countries of the Kyoto Protocol for both GHGs. These are countries which are not subject to the target emission reductions in Annex B of the international agreement. As these countries experienced economic development, per capita agricultural emissions of both methane and income per capita increased until the turning points were reached and started to decline. Controlling for income, the dummy variables for years indicate higher emissions.

On the other hand, the Annex I countries, those that have committed to reductions in emissions of the six greenhouse gases by ratifying the Kyoto Protocol, exhibit a U-shaped EKC for both GHGs. This means that emissions have been decreasing with income but have increased again after a critical point. However, most Annex I countries had already experienced much of their economic development before 1990. Without additional data, it is difficult to ascertain what the shape of this EKC implies for Annex I countries. While the cross-section of countries used was large, the time series only spanned four years as the emission data is only collected every 5 years in 1990, 1995, 2000 and 2005. Even though the protocol went into force, the true test of the effectiveness lies in comparing the numbers in 2010 which reflects the first commitment period of 2008-2012.

The estimation of the augmented EKC model proved to be rather difficult. While the inclusion of additional independent variables makes the EKC seemingly less robust (Harbaugh et al., 2002), it is not reasonable to claim that the income variables pick up all variations in environmental emissions using the conventional EKC model. Omitted variable bias is a serious problem that cannot be ignored. In light of the study by Kumazawa & Callaghan (2010) which focused on augmenting the conventional EKC to show the impact of industrial production on the emissions of carbon dioxide, I estimated the augmented EKC for agricultural production on the emissions of methane and nitrous oxide in the industry.

Additional variables included in the augmented EKC model are the number of livestock, chemicals (fertilizers, pesticides, herbicides) used and the number of organic farms, along with a few others. However, these variables are not available for numerous countries and in the same years as the emission data. The resulting sub-sample used was for 55 countries of the original 131 countries, which are disproportionately Annex I countries and excludes a high emission non-Annex I country, China. This is one of the shortcomings of this research,

that data is not readily available for all countries for various aspects of agricultural production and for all known sources of methane and nitrous oxide.

The results of the augmented EKC model are mixed. For example, livestock numbers only contribute to methane emissions in Annex I countries. The number of organic farms has a positive and statistically significant impact on emissions of both CH_4 and N_2O, only in industrialized nations. This variable may not be measuring the organic practices of such farms and needs further analysis. Nitrous oxide emissions are contributed primarily through fertilizer and pesticide use of non-Annex I countries.

The implication of this research is that there is hope for organic agricultural practices which will help to mitigate the emissions of methane and nitrous oxide, which are more harmful and prevalent in agriculture compared to carbon dioxide. Engaging in sustainable agricultural practices will not only be healthy for consumers but will be more productive for farmers if they creatively choose methods that reduce greenhouse emissions and are environmentally friendly. The Kyoto Protocol's effectiveness in the future also lies in incorporating the role of developing nations in the reduction process. Finding the balance between these will help reduce the emissions of both methane and nitrous oxide in agriculture.

7. Appendix

Country	2008-2012 Target (% of 1990 baseline emission levels)	Ratification Date
Australia	+8%	2007
Austria	-8%	2002
Belarus	--	2004
Belgium	-8%	2002
Bulgaria	-8%	2002
Canada	-6%	2002
Croatia	-5%	2007
Czech Republic	-8%	2001
Denmark	-8%	2002
Estonia	-8%	2002
European Union	-8%	2002
Finland	-8%	2002
France	-8%	2002
Germany	-8%	2002
Greece	-8%	2002
Hungary	-6%	2002
Iceland	+10%	2002
Ireland	-8%	2002
Italy	-8%	2002
Japan	-6%	2002
Latvia	-8%	2002
Liechtenstein	-8%	2004
Lithuania	-8%	2003

Luxembourg	-8%	2002
Monaco	-8%	2006
Netherlands	-8%	2002
New Zealand	0%	2002
Norway	+1%	2002
Portugal	-8%	2002
Romania	-8%	2001
Russian Federation	0%	2004
Slovakia	-8%	2002
Slovenia	-8%	2002
Spain	-8%	2002
Switzerland	-8%	2003
Turkey	--	2009
Ukraine	0%	2004
United Kingdom	-8%	2002
United States	-7%	Not Yet Ratified

Table A-1. Annex I Countries with Emission Targets in Annex B of the Kyoto Protocol

Albania	Gabon	*Pakistan*
Algeria	Georgia	Panama
Angola	*Germany*	Paraguay
Argentina	Ghana	*Peru*
Armenia	*Greece*	Philippines
Australia	Guatemala	*Poland*
Austria	Haiti	*Portugal*
Azerbaijan	Honduras	Qatar
Bahrain	*Hungary*	Republic of Korea
Bangladesh	Iceland	Republic of Macedonia
Belarus	*India*	Republic of Moldova
Belgium	*Indonesia*	*Romania*
Benin	Iran	*Russian Federation*
Bolivia	Iraq	*Saudi Arabia*
Bosnia & Herzegovina	*Ireland*	Senegal
Botswana	*Israel*	Singapore
Brazil	*Italy*	*Slovakia*
Brunei Darussalam	Jamaica	*Slovenia*
Bulgaria	Luxembourg	*South Africa*
Cambodia	Japan	*Spain*
Cameroon	*Jordan*	Sri Lanka
Canada	*Kazakhstan*	Sudan
Chile	Kenya	*Sweden*
China	Kuwait	*Switzerland*
Colombia	Kyrgyzstan	Syrian Arab Republic
Congo	*Latvia*	Tajikistan
Costa Rica	Lebanon	Tanzania
Côte d'Ivoire	Libya	*Thailand*
Croatia	*Lithuania*	Togo
Cuba	*Malaysia*	Trinidad & Tobago
Cyprus	Malta	*Tunisia*

Czech Republic	Mexico	Turkey
Democratic People's Republic of Korea	Mongolia	Turkmenistan
Democratic Republic of Congo	Morocco	Ukraine
Denmark	Mozambique	United Arab Emirates
Dominican Republic	Myanmar	United Kingdom
Ecuador	Namibia	United States of America
Egypt	Nepal	Uruguay
El Salvatore	Netherlands	Uzbekistan
Eritrea	New Zealand	Venezuela
Estonia	Nicaragua	Vietnam
Ethiopia	Nigeria	Yemen
Finland	Norway	Zambia
France	Oman	Zimbabwe

Table A-2. Countries with Emissions Data (Used in EKC Model in Tables 2 and 3) and Subset of Italicized Countries (Used in Augmented EKC Model in Tables 4 and 5)

Variable	Data Source	Year(s) Available	Countries Available
Agricultural Methane Emissions per Capita (thousand MtCO$_2$e)	World Development Indicator (Word Bank)	1990, 1995, 2000, 2005	133
Agricultural Nitrous Oxide Emissions Per Capita (thousand MtCO$_2$e)	World Development Indicator (Word Bank)	1990, 1995, 2000, 2005	133
Population	World Development Indicator (Word Bank)	1960-2009	215
Gross Domestic Product per Capita (constant 2000 $US)	World Development Indicator (Word Bank)	1960-2009	215
Fertilizer Consumption (kg per hectare of Arable Land)	World Development Indicator (Word Bank)	1990-2009	215
Dummy Variable for Annex I Status	Kumazawa & Callaghan (2010)	1980-2009	210
Arable Land (Hectares)	FAOSTAT (Food and Agriculture Organization of the United Nations)	1961-2009	234
Livestock (1000 Heads)	World Environmental Factbook (Euromonitor International)	2001-2007	71
Number of Organic Farms	World Environmental Factbook (Euromonitor International)	2001-2007	71
Pesticide Consumption (1000 tons)	World Environmental Factbook (Euromonitor International)	2001-2007	71
Herbicide Consumption (1000 tons)	World Environmental Factbook (Euromonitor International)	2001-2007	71
Production of Cereals (1000 tons)	World Environmental Factbook (Euromonitor International)	2001-2001	71

Table A-3. Variables and their Sources

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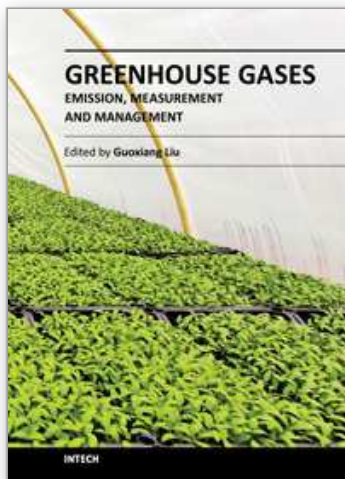
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Understanding greenhouse gas sources, emissions, measurements, and management is essential for capture, utilization, reduction, and storage of greenhouse gas, which plays a crucial role in issues such as global warming and climate change. Taking advantage of the authors' experience in greenhouse gases, this book discusses an overview of recently developed techniques, methods, and strategies: - A comprehensive source investigation of greenhouse gases that are emitted from hydrocarbon reservoirs, vehicle transportation, agricultural landscapes, farms, non-cattle confined buildings, and so on. - Recently developed detection and measurement techniques and methods such as photoacoustic spectroscopy, landfill-based carbon dioxide and methane measurement, and miniaturized mass spectrometer.

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