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Analyzing the Global CO_2 Emission per Capita using *Fractals*

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ABSTRACT

This paper analyzes the pattern of global CO_2 emission (GCE) per capita from 1960 to 2010. GCE data are treated as a fractal with consideration of the natural cycle of CO_2 in the atmosphere. In this state, GCE obeys the self-similarity, irregularity and ruggedness behavior. To identify that this natural state is preserved as well as the possible reasons if deviation from this state is observed is subjected to fractal dimension analysis (FDA). From the GCE data, annual fractal dimensions (FD) were calculated and plotted against time. The same set of data was tested for fractality identifying countries with high and low per capita GCE. Results showed that the frequency distribution plot of GCE exhibited a memoryless function which implied that GCE is expected to increase regardless of any interventions and levels of past and current emissions. Meanwhile, the FD plot showed a damped oscillation function which has direct implication to the resistance of countries on emission protocols. When this damping persist until a steady state is achieved, recovering the pre-industrialization levels of GCE is highly improbable. Moreover, calculated FD's of GCE is embedded at $1<FD<2$. This means that increasing GCE is attributed to two factors: high tourism activity and oil – production.

Keywords: *CO_2 emission, Fractal, Fractal dimension, tourism, oil-production*

INTRODUCTION

Fractals are observed in almost all types of phenomena. It occurs more often in nature than on regular shapes. They have the following characteristics of self-similarity, ruggedness, irregularity and fractal dimension (FD). Benoit Mandelbrot posited that the geometry of nature is indeed fractal and that it exhibits the aforementioned characteristics (Mandelbort, 1967).

In its natural state, CO_2 concentrations in the atmosphere should exhibit *fractal* behavior under natural exchanges of the carbon cycle. However, these concentrations have been increasing since the pre-industrialization period in 1850 (Knorr, 2009). For the past century, the rate of cumulative anthropogenic emissions was observed to be 40% higher in concentrations since pre-industrialization (IPCC, 2013). These changes may have caused deviation of the fractal nature of the concentration of CO_2 in the atmosphere resulting to changes in atmospheric factors related to CO_2 emissions such as global surface temperature and sea level. In fact, global CO_2 emission (GCE) had become a major concern since irreversible fluctuations of these emissions have been reported to result in an irreversible climate change (IPCC, 2014).

Early models that assessed the increasing trend of global CO_2 emission suggested many reasons to include population growth, economic growth, as well as energy consumption. Among these models, environmental Kuznets's curve (EKC) had been intensively researched and debated. While EKC presents acceptable results concerning local emission, global emission proved otherwise, hence EKC cannot be generally accepted at the global level (Borghesi and Vercelli, 2003).

Similarly, several studies had focused on forecasting that generated long term forecasts of CO_2 emission (Holtz-Eakin and Selden, 1995; Schmalensse et al., 1998), future distribution of CO_2 emission (Aldy, 2006; Aldy, 2007), as well as energy efficiency in relation to examining convergence of CO_2 emission (Graus, et al., 2007; Persson et al., 2007). Similarly, cross – country convergence in CO_2 emission studies had gained interests from policymakers implicated by future climate change policies (Aldy, 2006; Ezcurra, 2007; Romero-Avila, 2007; Stegman, 2005; Panopoulou and Pantelidis, 2007). However, Ramanathan (2002) argued that these methodologies were limited to consider only economic activities in describing environmental performance. More recent studies, however, examined the nexus of these variables and have reported that the influence of these variables may have unidirectional and/or bidirectional causality (Omri, 2013; Shahbaz et al., 2013; Chandran and Tang, 2013).

In this study, a different approach in the analysis of global CO_2 emission (GCE) and its future trend is employed. This method assumed that global CO_2 emission per capita is a natural phenomenon having characteristics of *fractals*. First, the analysis carried out a test of *fractality* achieved using Ryan – Joiner test. Second, annual fractal dimension (FD) from 1960 – 2010 is calculated and FD vs. time plot is obtained to show the fractal dimension trend. The significance of the first test explores the possible reasons of the deviation of current global CO_2 emission and clustering of high and low CO_2 emission. The second test explores the number of and possible factors that have a major contribution to the deviation as well as the future direction of the global CO_2 emission in relation to these factors. This is a departure from the commonly employed methodologies as such it delimits the identified number of factors affecting the deviation of global CO_2 emission from its natural state.

Review of Related Literature

According to the data, CO_2 concentrations in the atmosphere have been increasing over the past century at the onset of industrialization era. Energy demand had soared gearing toward economic development worldwide (IEA, 2013). However, environmental degradation become noticeable, particularly on the concerns of climate changes experienced in many parts of the world, that efforts of reducing CO_2 emissions put in place the Kyoto Protocol in 1990.

Many of the analytical methods employed to address or to identify factors affecting the increasing trend of global CO_2 emission as well as the environmental performance of a country were based on economic variables. Even those extended models focused on the integral effect of two or more economic variables (Omri, 2013; Shahbaz et al., 2013; Acaravci and Ozturk, 2010; Ghosh, 2010; Yavuz and Yilanci, 2012). Typically, the inverted U – shaped function, called Kuznets's curve was used to describe the relationship between environmental degradation and economic development (Grossman and Krueger, 1993). This model posited that as economy increase pollution also increases until a certain income level is reached. Beyond this level, the balance shifts as income increases and pollution declines as people put a high value on a cleaner environment, clean technologies, and regulations become more effective (Dasgupta et al., 2002). While the EKC model had gained momentum in tests of its hypothesis, Borghesi and Vercelli (2003) argued that EKC could not be generally accepted at a global level. Moreover, it is argued that economic variables used to investigate the increasing trend of global CO_2 emission only provide a partial picture in describing environmental performance (Ramanathan, 2002). A thorough survey conducted by Rodriguez and Pena-Boquete (2014) suggested that evidence were inconclusive about the validity of the EKC hypothesis.

On the other hand, the use of fractals in the analysis of natural phenomena is not a new concept. The analysis was carried in many contexts to include applications in physics and mathematics (McCauley, 1993) particularly to natural phenomena with time series data (Cervantes – de la Torre et al., 2013). The methods employed in this study included (a) test of *fractality*, which used the log test of mean global CO_2 emission per capita similar to those employed in the study of club convergence (Panopoulo and Pantelidis, 2007; Jobert et al., 2010; Camarero et al., 2013; Barassi et al., 2011; Yavuz and Yilanci, 2012); (b) measurement of annual fractal dimension and plot the trend in its change. In fractal theory, the fractal dimension indicates either as a topological dimension, an embedded object, or box-counting dimension (Wild, 2010). In this study, fractal dimensions translate to the number of factors embedded in the dimension that may have causality to the increasing global CO_2 emission (or decreasing fractal dimension).

MATERIALS AND METHODS

This section presents the methods used in analyzing the global CO_2 emission per capita of 253 countries from 1960 to 2010 outlined as follows:

Test for Fractality

The test for *fractality* can be done in two ways using the following theorems.
A variable *x* is said to be fractal if and only if the

(1) $log\left(\frac{x}{\theta}\right)$ exhibits *exponentiality*, where θ is the minimum; or

(2) histogram of e^{y} exhibits fractality where x is the variable considered and $y = log\left(\frac{x}{\theta}\right)$.

If the data satisfies either of the two conditions mentioned, the data shall be compared to theoretical exponential data and perform a Ryan-Joiner Test.

Measurement of the Fractal Dimension

The annual fractal dimension λ can be measured by

$$\lambda = 1 + \frac{1}{\bar{y}}$$

where $\bar{y}$ is the mean.

Measurement of the Trend of the fractal dimension

The calculated annual fractal dimension is plotted versus time (in year). There are three regions identified based on the average slope. The slope of each trend is calculated via regression analysis using Minitab.

RESULTS AND DISCUSSIONS

From the raw data of annual global CO_2 emission per capita, a histogram of frequency vs. CO_2 emission per capita was generated as shown in Figure 1.

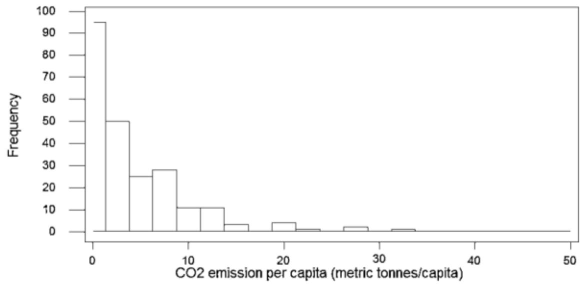

Figure 1. Frequency distribution of mean CO_2 emission per capita (1960 - 2010).

Evidently, its frequency distribution behaves exponentially where its probability distribution is described as

Eq. 4. $$f(x) = \beta \exp(-\beta x),$$

where β is constant and x is a random variable. The probability for $x > x_0$ is therefore

Eq. 4.2 $P(x > x_0) = 1 - \beta exp(-\beta x)$.
Eq. 4.3 $P(x > x_0 + t \mid x > t) = P(x > t)$, where $x = x_0 \ldots x_n$

where t is some constant (Pal et al., 2006). Moreover, using Ryan - Joiner test provided a relatively high mean regression coefficient ($r^2 = 90.5\%$). This further confirms the *exponentiality* of the probability distribution that is there are more countries having CO_2 emission between 0 to 10 metric ton per capita and fewer are found in the upper extreme.

Furthermore, as *n* becomes large, the probability approaches to unity. This is a characteristic of a "*memoryless*" function. Qualitatively, "*memoryless"* functions depict events in the future that does not rely on their past events. Strictly speaking, it is determined by its most present event (Barucha – Reid, 1960; Papoulis, 1984). This characteristic function of global CO_2 emission per capita indicates that it will have an increasing trend regardless of its current and past status. Additionally, this has serious implications to the current intervention of humans in terms of emission reduction of major CO_2 contributing countries. That is, no amount of intervention such as emission protocols, the agreement between countries that will solve the problem of continued CO_2 emission. We point out that regardless of the level of emission, this would impact on climate change (IPCC, 2007; Gardiner and Hartzell-Nichols, 2012) however, this too hurts economic growth and sovereignty of a country as such that there is a strong causality between economic growth and CO_2 emissions (Wang et al., 2017). In particular, compliance with these protocols is dependent on national circumstances such as economic structure, resource endowment, and policy choices (Fankhauser and Jotzo, 2017). For example, the US, Japan, and Canada had withdrawn from these agreements for economic reasons among others. Likewise, member countries of the European Union (EU) failed in achieving their targeted reduction emissions posing uncommittable stringent climate policies. Also, there are only 63 out of 144 countries have ratified the DOHA amendment including the staunchest advocate European Union (EU) (Fankhauser and Jotzo, 2017) as well as there are 13 countries yet to ratify the Paris agreement (Apparicio and Sauer, 2018) before its full implementation.

The characteristic function above suggests that the current CO_2 emission per capita is purely independent and does not depend on any of its adjacent data from the past. This may reflect the results of Aldy (2006) on diverging CO_2 emission per capita for 88 countries using Markov Chain transition matrix. Similarly, the divergence of CO_2 emissions per capita in OECD countries and EU countries were evident (Barassi et al., 2007; Jobert et al., 2010).

The divergence of CO_2 emission per capita of countries results in a clustering of countries where emissions are relatively the same. Employing theorem 2, it is found out that countries cluster each other according to their similarities in CO_2 emission per capita as shown in Figure 2. This figure further identifies countries clustered in the lower and upper extreme. Of the 253 countries evaluated, countries appearing consistently in the top rank in terms of CO_2 emission per capita are Qatar, United Arab Emirates, Kuwait, Brunei, and the United States of America (USA). During the start of the 1980s, Bahrain and Aruba entered the top list.

This clustering of low and high per capita CO_2 emission was described on Panopoulou (2007) as club convergence. Under this clustering, countries were identified to converge to the point of steady state emission of CO_2. Countries of high emission of CO_2, for example, tend to have emissions on the average of 28.2 metric ton per capita. The significant activities identified for these clustered countries point to high oil – production and high tourism activity. We note that the identified countries of the Middle East as generally oil – producing countries (i.e. Qatar, UAE, Kuwait, Bahrain) as well as Brunei and USA. They are commonly listed in the top rank oil – production countries (World Bank, 2014; Bekhet et al., 2017). On the other hand, the major economic driver of Aruba is tourism which has direct relation to high fossil fuel/ energy consumption and corresponds to 28.1% of GDP (WTTC, 2018). Tourism induced CO_2 emission has been predicted to contribute 7.5% of global CO2 emission by 2035 (UNWTO-UNEP-WMO, 2008; Chen et al., 2018).

Moreover, a trend on the fractal dimension is graphed as shown in Figure 3. It is observed to show a dramatic decline in the fractal dimension between 1960 and 1973. Prior to this period, the natural cycle of global CO_2 level fluctuates and behaves as undamped oscillation. However, the fluctuation of the fractal dimension shown in Figure 3 is behaving like a damped oscillation whose function can be expressed as where A and γ are the amplitude and damping coefficient respectively. It is imperative from equation 4.4 and from Figure 3 that its fractal dimension amplitude is defined by damping factor/s and is decreasing (fractal dimension) as time progresses. This damping factor/s suggests resistance causing the reduced amplitude of this fractal dimension oscillation. For example, opposition (resistance) to Kyoto Protocol by developing and developed countries caused elevated CO_2 emissions as it did not speak the needed arbitration on the reduction of CO_2 amenable to these countries (Ferry, 2010).

Eq. 4.4 $$f(t) = A\exp(-\gamma t)\sin(\omega t + \varphi),$$

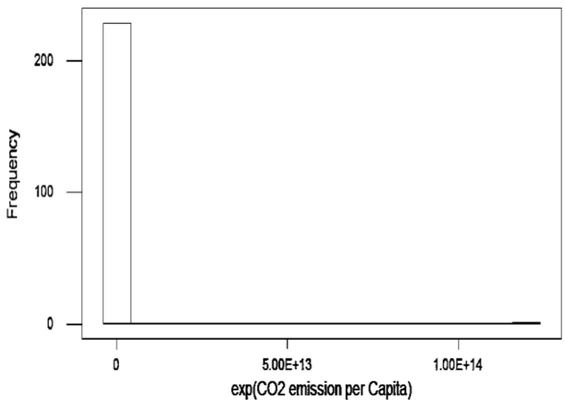

Figure 2. Histogram of the Exponential of mean CO_2 emission per capita (1960 - 2010)

As pointed out earlier, the stricter policies imposed by the emission protocols resulted in withdrawal and/or non – committal to reduction agreements. In effect, this may pose unregulated CO_2 emission that may further reduce the fractal dimension indicating a total deviation and irreversibility from the natural state of CO_2 exchange in the atmosphere. This is a manifestation of possible crossing critical tipping points where major irreversible changes in the Earth system is a risk, such as a sea level rise and global temperature; hence the Paris agreement necessitates the global average temperature to well below 1.5°C (Frieler et al., 2012).

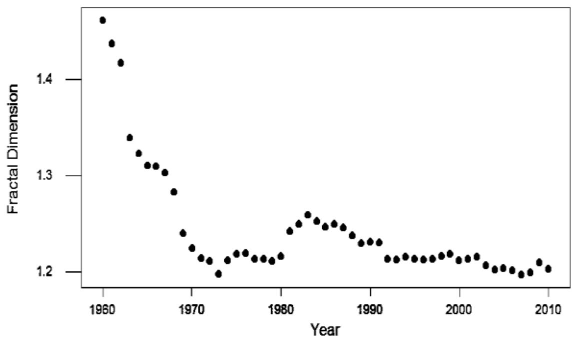

Figure 3. The plot of the change of the fractal dimension over the course of 5 decades

CONCLUSION

In light of the finding of the study, high tourism activity and high oil production have a direct bearing on per capita GCE. This is reminiscent of the economic value of these activities. For example, tourism activities have resulted in increasing employment as the demand for the service sector increases. Causality between economic growth and increase in CO_2 emission exists. These activities were identified to cause the deviation from natural exchanges of CO_2 in the atmosphere at least in our model. Consequently, per capita GCE likely to increase exponentially as countries do not put regard to past and current emission level as well as on implemented interventions. Also, these interventions only direct toward clustering of countries where per capita CO_2 emissions are relatively the same. Moreover, resistances to interventions points to non – recovery of a pre-industrial level per capita GCE. These resistances may pose a risk of crossing critical tipping points in natural processes (i.e., glacier melt, sea level rise) such as the effect of elevated GHG's to the global temperature beyond the articulated agreement of 2°C.

The use of fractals, on the other hand, allows us to identify the major confounding factors, as in the case of GCE per capita high tourism activity and oil production, by looking into the fractal dimension (i.e., $1 < FD_{GCE} < 2$ means there are two major confounding factors affecting GCE per capita). This is the relative power of the method in the analysis of events and processes and the observable deviation from them by looking at the changes of the fractal dimension (FD).

REFERENCES

Acaravci A, Ozturk I. On the relationship between energy consumption, CO_2 emissions, and economic growth in Europe. Elsevier: Energy 2010; 35: 5412 – 5420

Aldy JE. Per capita carbon dioxide emissions: Convergence or divergence? Environmental and Resource Economics 2006; 33(4): 533-555.

Aldy JE. Divergence in state-level per capita carbon dioxide emissions. Land Economics 2007; 83(3): 353-369

Apparicio, S. and Sauer, N. Which countries have not ratified the Paris agreement? https://www.climatechangenews.com/2018/07/12/countries-yet-ratify-paris-agreement/

Barassi MR, Cole MA, and Elliot RJ. Stochastic divergence or convergence of per capita carbon dioxide emissions: Re-examining the evidence. Environmental and Resources Economics 2008; 40: 121 – 137

Bekhet, H. A., Matar, A., & Yasmin, T. (2017). CO 2 emissions, energy consumption, economic growth, and financial development in GCC countries: Dynamic simultaneous equation models. Renewable and Sustainable Energy Reviews, 70, 117–132. doi:10.1016/j.rser.2016.11.089

Borghesi S, Vercelli A. Sustainable globalisation. Ecological Economics 2003; 44:77-89

Camarero M, Picazo – Tadeo AJ, Tamarit C. Are the determinants of CO_2 emissions converging among OECD countries? Elsiever: Economic Letters 2013; 118 (1): 159 – 162.

Cervantes – de la Torre F, Gonzalez – Trejo JI, Real – Ramirez CA, Hoyos – Reyes LF. Fractal dimension algorithms and their application to time series associated with natural phenomena. Journal of Physics Conference Series 2013; 475 (1): 1 – 10 DOI: 10.1088/1742-6596/475/1/012002

Chandran VGR, Tang CH. The impacts of transport energy consumption, foreign direct investment, and income on CO_2 emissions in ASEAN – 5 economies. Elsevier: Renewable and Sustainable Energy Reviews 2013; 24: 445 – 453

Chen, L., Thapa, B., and Yan, W. (2018). The Relationship between Tourism, Carbon Dioxide Emissions, and Economic Growth in the Yangtze River Delta, China Sustainability 2018, 10, 2118; DOI:10.3390/su10072118

Ezcurra R. Is there cross-country convergence in carbon dioxide emissions? Energy Policy 2007; 35: 1363-1372

Ferrey S. The failure of international global warming regulation to promote needed renewable energy. Boston College Environmental Affairs Law Review 2010; 37 (1): 67 – 126

Frieler, K., Meinshausen, M., Golly, A., Mengel, M., Lebek, K., Donner, S. D., & Hoegh-Guldberg, O. (2012). *Limiting global warming to 2 °C is unlikely to save most coral reefs. Nature Climate Change, 3(2), 165–170.* DOI:10.1038/nclimate1674

Gardiner, S. M., and Hartzell-Nichols, L. (2012) Ethics and Global Climate Change. *Nature Education Knowledge* 3(10):5

Graus WHJ, Voogt M, Worrell E. International comparison of energy efficiency of fossil power generation. Energy Policy 2007; 35:3936-3951

Ghosh S. Examining carbon emissions economic growth nexus in India: A multivariate cointegration approach. Elsevier: Energy Policy 2010; 38: 3008 – 3014.

Holtz-Eakin D, Selden TM. Stoking the fires: CO_2 emissions and economic growth. Journal of Public Economics 1995; 57, 85-101

IPCC (Intergovernmental Panel on Climate Change). *Climate Change 2007: The Physical Science Basis*. Cambridge, UK: Cambridge University Press, 2007

IPCC. Climate Change 2014: Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. 2014; 1 – 151

IPCC. Summary for Policymakers. In: Climate Change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA 2013; 1 – 27

Jobert K, Karanfil F, Tykhonenko A. Convergence of per capita carbon dioxide emissions in EU: Legend or reality? Energy Econ 2010; 32(6): 1364 - 1373 Elsevier

Knorr W. Is the airborne fraction of anthropogenic CO_2 emissions increasing? Geophysical Research Letters 2009; 36 (21): 1 – 5

Mandelbort B. How long is the Coast of Britain? Statistical self-similarity and fractional dimension, Science, New Series 1967; 156(3775): 636-638

McCauley JL. Chaos, dynamics, and fractals: An algorithmic approach to deterministic chaos. Cambridge Nonlinear Science Series Vol. 2, Cambridge England: Cambridge University Press 1993

Omri A. CO_2 emissions, energy consumption, and economic growth nexus in MENA countries: Evidence from simultaneous equation models. Energy Economics 2013; 40: 657 – 664

Pal N, Jin C, Lim WK. Handbook of exponential and related distributions for engineers and scientists. Chapman & Hall/CRC, Florida, USA. 2006; 151 – 160

Panopoulou E, Pantelidis T. Club convergence in carbon dioxide emissions. Environmental and Resource Economics 2009; 44(1): 47 – 70

Persson TA, Colpierb UC, Azar C. Adoption of carbon dioxide efficient technologies and practices: An analysis of sector-specific convergence trends among 12 nations. Energy Policy 2007; 35: 2869-2878

Ramanathan R. Combining indicators of energy consumption and CO_2 emissions: a cross-country comparison. International Journal of Global Energy Issues 2002; 17: 214–227

Romero-Avila D. Convergence in carbon dioxide emissions among industrialized countries revisited. Energy Economics 2007.

Schmalensse R, Stiker TM, Judson RA. World carbon dioxide emissions: 1950-2050. The Review of Economics and Statistics 1998; 80(1), 15-27

Shahbaz M, Hye QMA, Tiwari AK, Leitao C. Economic growth, energy consumption, financial development, international trade and CO_2 emission in Indonesia. Renewable and Sustainable Energy Resource Reviews 2013; 25: 109 – 121

Stegman A. Convergence in carbon emissions per capita. Centre of Applied Macroeconomic Analysis Working Paper, The Australian National University 2005

UNWTO-UNEP-WMO. *Climate Change and Tourism: Responding to Global Challenge*; The World Tourism Organization and The United Nations Environment Programme: Madrid, Spain, 2008.

Wild J. Dimensioner och fraktal geometri. 2010 February

World Bank. GDP Annual Growth Rate. Retrieved from: data.worldbank.org/indicator; 2014.

World Travel and Tourism Council: Travel & Tourism Economic Impact 2018 – ARUBA https://www.wttc.org//media/files/reports/economic-impact-research/countries-2018/aruba2018.pdf

Yavuz NC, Yilanci V. Convergence in per capita carbon dioxide emissions among G7 countries: A TAR Panel Unit Root approach. Springer Science: Environ Resource Eco 2012 doi.10.1007/s10640-012-9595-x

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