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Performance of Combined Ozone and Fenton Process in Treating Different Leachate Concentrations

Hamidi Abdul Aziz[1], *Salem S. Abu Amr*[2]

Abstract. Background: Leachate pollution is one of the main problems in landfilling, and researchers have yet to find an effective solution to this problem. The technology that can be used may differ based on the type of leachate produced. The most problematic parameters in leachate are chemical oxygen demand (COD), ammonia, and color. Material and Methods: The performance of ozone/Fenton in advanced oxidation process (AOPs) in treating stabilized leachate was investigated. The optimal dosages of Fenton reagent (0.05 mol L-1 (1,700 mg/L) H2O2 and 0.05 mol L-1 (2,800 mg/L) Fe2+) were determined through preliminary experiments and added to the leachate sample into the ozone reactor. The input ozone concentration in a 2 L leachate sample was 80 g/m3 NTP ± 0.5% under 1 bar pressure. The initial COD varied between 250 and 2360 mg/L, color varied between 470 Pt. Co. to 4530 Pt. Co., and NH3-N varied between 150 mg/l to 1170 mg/L. Results: the maximum removal efficiency was 87% for COD, 100% for color, and 22% for NH3–N at lowest leachate concentration. The lowest amount of consumed ozone (1.28 KgO3/ Kg COD) corresponded to the initial concentration of COD (2000 mg/L) with 60% removal of COD during 1 h ozonation. The biodegradability (BOD5/COD) improved from 0.09 in raw leachate to 0.27 at 500 mg/L initial COD. Conclusion: The current study revealed that the use of ozone/Fenton (O3/H2O2/Fe2+) in AOPs is more efficient in removing COD and color in low concentrations of semi-aerobic stabilized leachate and in improving biodegradability.

Keywords: Ozonation, Advanced oxidation, Initial concentration, Stabilized leachate, Biodegradability

1. Introduction

Sanitary landfilling is the most common and desirable method for controlling urban solid waste. It is also considered the most economical and environmentally acceptable method for eliminating and disposing municipal and industrial solid wastes (Tengrui et al. 2007). However, sanitary landfills are also prone to polluting the immediate environment. Landfill leachate is the liquid that has seeped through solid waste in a landfill, gaining extracted, dissolved, or suspended materials in the process (Christensen et al. 2001). Landfill leachate is a potentially polluting liquid unless returned to the environment in a carefully controlled manner (Scottish Environment Protection Agency, (SEPA 2003). Leachate contains high amounts of organic compounds, ammonia, heavy metals, a complex variety of materials, and other hazardous chemicals, and is recognized as a potential source of ground and surface water contamination (Schrab et al.

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1993; Christensen et al. 2001; SEPA 2003). Old (Stabilized) leachate characterized as a very low biodegradability which is difficult to biologically proceeds. The variation of biodegradability (BOD5/COD) in leachate was attributed to the different types of leachate that were classified based on landfill age and leachate decomposition. The BOD5/COD ratio in young (<5 years), intermediate (5–10 years), and stabilized (>10 years) leachate was reported as >0.3, 0.1–0.3, and <0.1, respectively (Schiopu et al., 2010; Naumczyk et al. 2012).

Treatment of these leachates in classical wastewater treatment plants is rarely practiced due to the nature and high levels of pollutants present in them (i.e. high COD and ammonia and low biodegradability). Researchers throughout the world are still searching for a total solution to leachate problem. To date, multiple stage treatments are required to remove simultaneously pollution from leachate. In literatures, different physiochemical and biological treatment applications on leachate treatment have been reported such as; Fenton, photo-Fenton, electro-Fenton, coagulation, electro-coagulation, ozonation, adsorption, ion exchange, Persulfate and biological processes. (Aziz , et al., 2011; Bashir et al., 2011;Mohajeri et al., 2010a, b; Primo et al., 2008; Moravia et al., 2012;Ilhan et al., 2008; Tizaoui et al., 2007; Shabiimam and Dikshit, 2012; Deng and Ezyske ,2011). There is no single method which could effectively remove all the pollutants simultaneously.

Ozone has recently received much attention in landfill leachate treatment technology due to its powerful chemical oxidant and high capacity for oxidation (Huang et al. 1993; Rice et al. 1997; SEPA 2003; Wu et al. 2004). Several applications of ozone on landfill leachate treatment have been conducted (Tizaoui et al. 2007), obtaining 27% and 87% removal for chemical oxygen demand (COD) and color, respectively, during the ozonation of leachate. Hagman et al. (2008) obtained 22% COD reduction. Rivas et al. (2003) conducted 30% depletion of COD.

Although ozone is effective in stabilized leachate treatment, its effectiveness will be improved using advance oxidant materials and techniques. By employing hydrogen peroxide in advanced oxidation during the ozonation process, Tizaoui et al. (2007) obtained a COD removal of 50%, whereas Hagman et al. (2008) obtained a COD removal from 22% (ozone alone) to 50%. Goi et al. (2009) obtained a COD removal from 24% to 41% at varying pH from 4.5 to 11, respectively. Ozonation and Fenton are now being used increasingly in landfill leachate treatment. These processes are generally applied as pre-treatment (Gau and Chang 1996; Geenens et al. 2000; Haapea et al. 2002; Kamenev et al. 2002; Fang et al. 2005; Goi et al. 2009; Cortez et al. 2010) or post-treatment (Iaconi et al. 2006; Vilar et al. 2006; Goi et al. 2009) stages in the consequence of improving the efficiency of the treatment. Recently, Abu Amr and Hamidi (2012) improved COD removal efficiency from 15% used ozone alone to 65% used Ozone/Fenton in AOPs. However, the performance of this new process in different initial leachate concentrations has not been investigated. Furthermore, the effectiveness of Ozone/Fenton process in enhance biodegradability of stabilized leachate was not well documented. In the present study, a new treatment process ($O_3/H_2O_2/Fe^{2+}$) was introduced by employing the Fenton reagent in the advanced oxidation process for the treatment of stabilized solid waste leachate by ozone as one treatment stage. The main objective of the present study is to investigate the performance of employing Ozone/Fenton reagent in advanced oxidation in treating different concentrations of semi-aerobic stabilized leachate.

2. Materials and methods

2.1. Leachate sampling and characteristics

Leachate samples were collected from a leachate aeration pond of a semi-aerobic stabilized landfill leachate at Pulau Burung Landfill Site (PBLS), Byram Forest Reserve in Penang, Malaysia. PBLS has an area of 62.4 ha, of which 33 ha are currently operational and receive about 2200 t of municipal solid waste daily. It is equipped with a natural marine clay liner and three leachate collection ponds (Bashir et al. 2011). On March 14 and June 17, 2011, approximately 20 L of leachate was collected manually and placed in plastic containers. The samples were transported immediately to the laboratory, characterized, and cooled at 4 ^{o}C to minimize the biological and chemical reactions. The average characteristics of the leachate used in the experiments are summarized in Table 1. Sample collection and preservation were done in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA), 2005.

Table 1. Characteristics of semi-aerobic landfill leachate from PBLS

Parameters	Value
COD (mg/L)	2360
BOD (mg/l)	70
NH_3-N (mg/L)	1170
Color (PT Co.)	4530
pH	8.5
Suspended solids (mg/L)	197
Conductivity, µS/cm	17,880

2.2. Experimental procedures

All experiments were carried out in a 2 L sample using an ozone reactor with height of 65 cm and inner diameter of 16.5 cm, supported by a cross column ozone chamber for enhancing ozone gas diffusion (Figure 1). Ozone was produced by a BMT 803 generator (BMT Messtechnik, Germany) fed with pure dry oxygen with the recommended gas flow rate of 200 ml/min ±10%. Input ozone concentration was 80 g/m^3 NTP ± 0.5% under 1 bar pressure. Gas ozone concentration (in g/m^3 NTP) was measured by an ultraviolet gas ozone analyzer (BMT 964). The water bath and cooling system <15 °C supported the ozone reactor. Fenton reagent (H_2O_2/Fe^{2+}) was employed in advanced oxidation during the ozonation of stabilized leachate. Hydrogen peroxide (H_2O_2, 30%) and ferrous sulfate heptahydrate ($Fe_2SO_4.7H_2O$, 278.02 g/mol) were used in preparing the Fenton reagent, and then added to the leachate sample into the ozone reactor. The optimal dosage of Fenton reagent (0.05 mol L^{-1} (1,700 mg/L) H_2O_2 and 0.05 mol L^{-1} (2,800 mg/L) Fe^{2+}) and 60 min ozonation at pH 7 were obtained through a set of preliminary experiments as follow: Fenton reagent (H2O2/Fe2+; with molar ratios of 0.5, 1, 2, 3, 4, 5, and 6) and 0.01 mol ferrous sulfate (Mohajeri et al., 2010) were immediately added into an ozone reactor before each run to achieve the highest performance ratio for the treatment of stabilized leachate. Molar dosages of Fenton reagent were gradually added while maintaining the optimal molar ratio (1:1 obtained from previous step) to determine the optimum dosage for the efficiencies of COD, color, and NH_3–N removal. Based on the optimum molar dosage of Fenton reagent, the initial pH of the leachate was gradually adjusted from 2 to 11 using 5 M sulfuric acid solution and 5 M sodium hydroxide solution. The reaction time was examined from 10 min to 180 min at the optimal pH value (7) Abu Amr and Aziz, (2012). Four each run, pH was adjusted after added Fenton reagent in to the sample immediately.

Different concentrations of leachate were used during the ozonation experiments. The initial COD varied between 250 and 2360 mg/L, the color varied between 470 Pt. Co. to 4530 Pt. Co., and NH_3-N varied between 150 mg/l to 1170 mg/l. The leachate concentrations were adjusted using the following equation (1):

$$C_1V_1 = C_2V_2 \quad (1)$$

where C_1 is the original concentration of COD before it was watered down or diluted, C_2 denotes the final COD concentration after dilution, V_1 is the volume to be diluted, and V_2 represents the final sample volume after dilution.

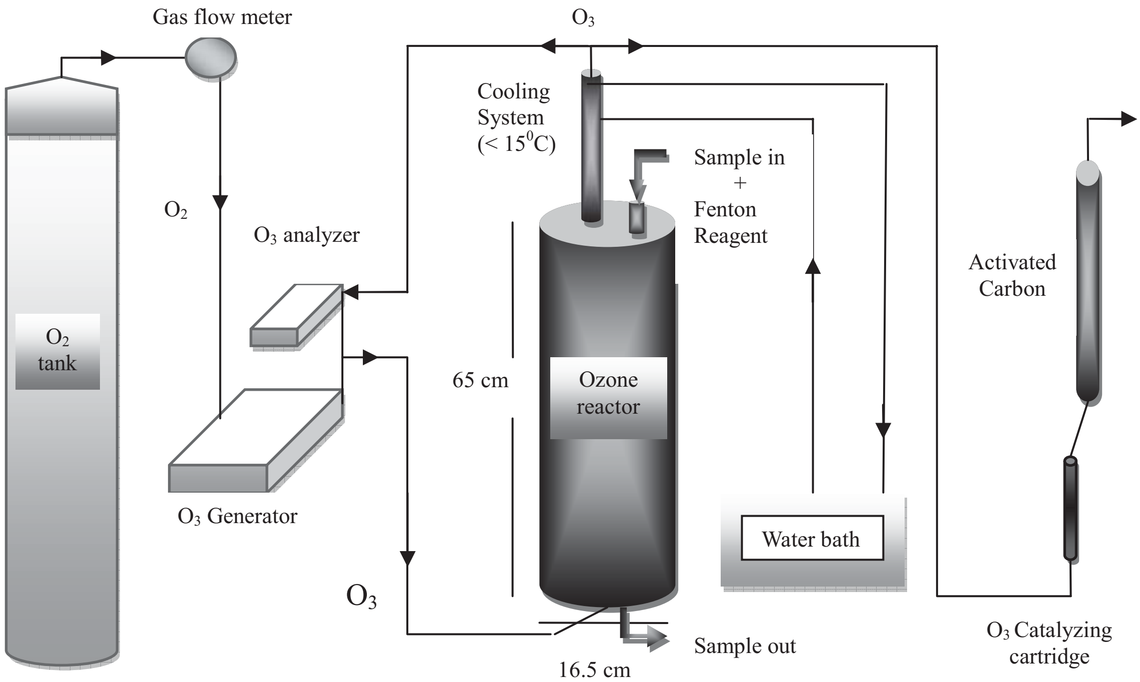

Figure 1. Schematic diagram of ozone equipment and experiments procedures.

2.3. Analytical Methods

COD, color, NH_3-N, and pH were tested immediately before and after each run of the experiments in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA 2005). The concentration of NH_3-N was measured by the Nessler Method using HACH DR 2500 spectrophotometer, whereas pH was measured by a portable digital pH/Mv meter. COD concentration was determined by the closed reflux colorimetric method using DR2800 HACH spectrophotometer. Color concentration was measured using DR 2800 HACH spectrophotometer. BOD_5 was measured according to Standard Methods (APHA 2005). The removal efficiency of COD, color, and ammonia were obtained using the following equation:

$$\text{Removal (\%)} = \left[C_i - \frac{C_f}{C_f} \right] \times 100 \qquad (2)$$

where $C_i - C_f$ are the initial and final COD, color and ammonia concentrations, respectively.

3. Results and Discussion

3.1. Treatment efficiency

To investigate the efficiency of employing ozone/Fenton in the advanced oxidation process for different concentrations of stabilized leachate treatment, a set of experiments with different initial COD concentrations were achieved in the ozone reactor by adding optimal Fenton dosage (0.05 mol L^{-1} (1,700 mg/L) H_2O_2 and 0.05 mol L^{-1} (2,800 mg/L) Fe^{2+}) at pH 7. Fenton is used for improving the oxidation potential during ozonation. The initial COD varies between 250 and 2360 mg/l. Figure 2 illustrates the removal efficiency of COD at different initial COD of stabilized leachate.

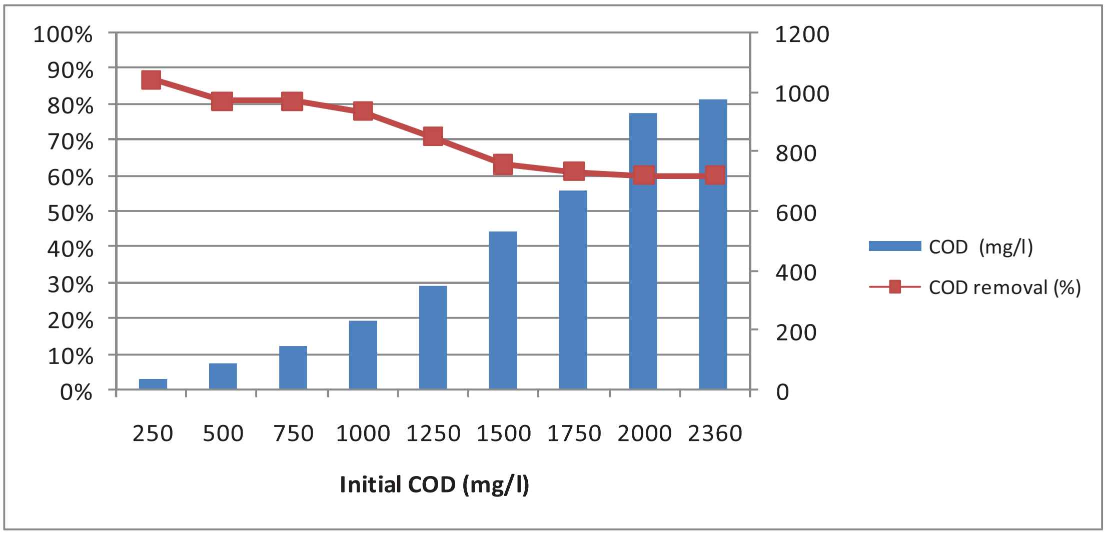

Figure 2. Effects of Initial COD concentration on removal of COD by Ozone/Fenton in the advanced oxidation process (O^3= 80, H_2O_2 = 1700 mg/l, Fe^{2+}= 2800 mg/l, pH= 8.3, RT= 60 min).

In the $O_3/H_2O_2/Fe^{2+}$ system, the Fenton ions reacted with H_2O_2, resulting in the formation of hydroxyl radicals (·OH) (Equation 3). •OH has the potential to destroy and degrade organic pollutants (Hermosilla et al. 2009).

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + OH^\bullet \qquad (3)$$

The reaction of ozone with H_2O_2 generates .OH radicals. H_2O_2 is also dissolved in water and dissociates into the hydroperoxide ion (HO_2^-), which rapidly reacts with ozone to initiate a radical chain mechanism that generates hydroxyl radicals (Staehelin et al. 1982; Glaze et al. 1987), as demonstrated in Equations 4 and 5.

$$H_2O_2 + 2O_32 \rightarrow OH^{\bullet} + 3O_2 \quad (4)$$

$$HO_2^{-} + O_3 \rightarrow HO_2^{\bullet} + O_3 \quad (5)$$

The removal efficiency ranged from 60% to 87%, whereas the maximum removal corresponded with the lowest initial COD concentration (250 mg/l). For color removal, the treatment efficiency was much better, which ranged between 95% and 100% (Figure 3). As shown in Figure 3, the total removal of color was obtained at less than 750 mg/l initial COD. However, the removal efficiencies of COD and color were more efficient at initial COD less than 1500 mg/l. The reaction of ozone with hydrogen peroxide gives rise to •OH radicals. H_2O_2 is also dissolved in water and dissociates into a hydro peroxide ion (HO_2^{-}), which reacts rapidly with ozone to initiate a radical chain mechanism that leads to hydroxyl radicals (Staehelin et al., 1982; Glaze et al., 1987). Several studies have been conducted on leachate treatment using ozone-based advanced oxidation processes (AOPs). Tizaoui et al. (2007) obtained 50% and 87% removal efficiency of COD and color, respectively, using H_2O_2 as advanced oxidation during the ozonation of stabilized leachate. Nevertheless, the removal efficiency of ammonia by system $O_3/H_2O_2/ Fe^{2+}$ is relatively low, which ranged from 12% to 22% at different initial concentrations of ammonia (150 mg/l to 1170 mg/l) (Figure 4).

In the Fenton treatment system, the optimal pH values for the degradation of organics range between 2 and 4.5 (Lopez et al., 2004; Deng, 2007; Mohajeri et al., 2010). However, ozonation is more efficient for leachate oxidation at high pH values under the indirect oxidation effects of hydroxyl radicals, which is more efficient than the direct reaction of the ozone molecule under an acidic condition (Langlais et al., 1991). The decreased removal efficiencies of all parameters at exceeding initial COD values may be attributed to increasing the amount of pollutants contribute to ozone consumption, thus inhibiting part of the ozone from reacting with target compounds. This phenomenon results in the reduced effectiveness of ozone when reacting with organic compounds (Tizaoui et al., 2007). Cortez et al. (2011) reported increased COD removal from 18% at pH 5.5 to 49% at pH 11. Similar results were obtained in the ozonation of landfill leachate with COD removal efficiencies of 24%, 29%, and 41% at the initial pH values of 4.5, 8.1, and 11, respectively (Goi et al., 2009).

Ammonia removal has become an important concern in leachate treatment, the latest development regarding the pollution control from solid waste transfer station and landfill in Malaysia reported NH_3–N as one of the parameters included in the standard discharge limits for pollutants in landfill leachate. The existence of high level of NH_3–N in landfill leachate over a long period of time is one of the most important problems routinely faced by landfill operators. The acceptable discharge limit according to Regulations 2009, Malaysian Environmental Quality Act 1974 [Act 127] was 5 mg/L. Nevertheless, the removal efficiency of ammonia by the $O_3/H_2O_2/ Fe^{2+}$ system was relatively low. The removal of ammonia is attributed to the contribution of sulfate at high pH (8–9) during the reaction process, given that ferrous sulfate (Fe_2SO_4) is a part of the Fenton reagent. Deng and Ezyske (2011) achieved 100% ammonia removal using a sulfate radical in the advanced oxidation of mature leachate at pH 8.3.

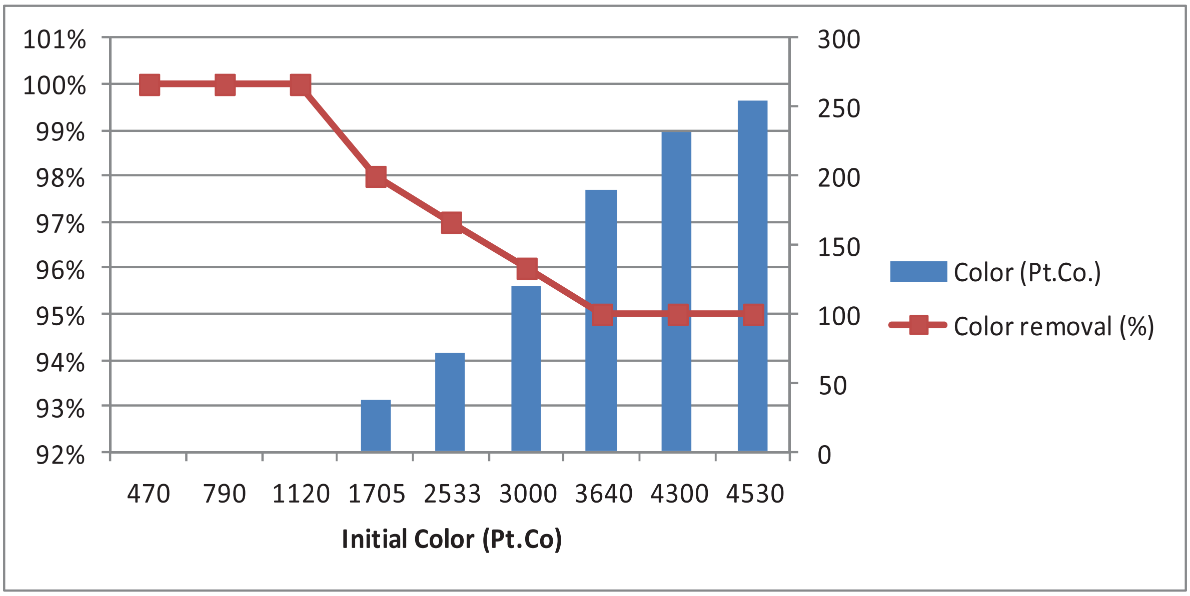

Figure 3. Effects of Initial Color concentration on removal of Color by Ozone/Fenton in the advanced oxidation process (O_3= 80, H_2O_2 = 1700 mg/l, Fe^{2+}= 2800 mg/l, pH= 8.3, RT= 60 min).

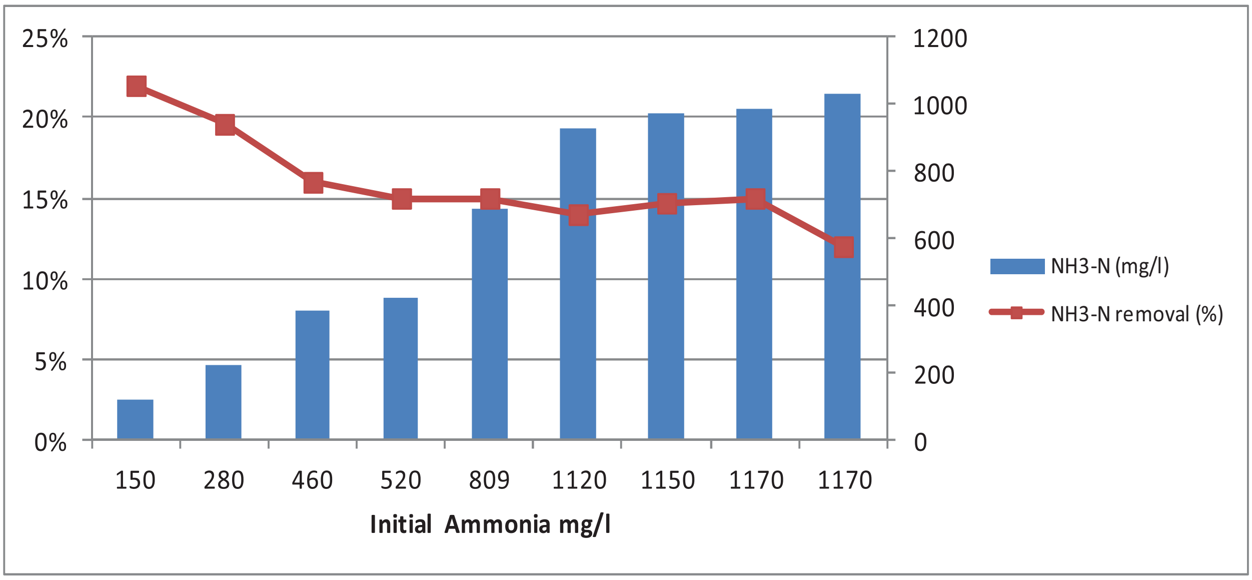

Figure 4. Effects of Initial NH_3-N concentration on removal of NH_3-N by Ozone/Fenton in the advanced oxidation process (O_3= 80, H_2O_2 = 1700 mg/l, Fe^{2+}= 2800 mg/l, pH= 8.3, RT= 60 min).

To evaluate the treatment efficiency of the combined ozone/Fenton system (Simultaneously) with other applications, three treatment processes for stabilized landfill leachate were performed, namely, ozone alone, Fenton alone (separately), and Fenton as pretreatment followed by ozone as post-treatment (sequentially). Figure 5 shows that the efficiency of ozone alone is insufficient for the removal of COD, colour, and ammonia (15%, 44%, and 0%, respectively). Compared with that of other processes, these lower values are attributed to the high concentration of organics in leachate containing a considerable amount of dissolved ozone in the aqueous phase from the beginning of the reaction (Rivas et al., 2003).Thus; the Fenton reagent is more efficient for leachate treatment than O3 alone. The performance of ozone after Fenton treatment is very low, which is consistent with the results reported by Goi et al. (2009). The removal efficiency is also improved by the advanced oxidation system ($O_3/H_2O_2/Fe^{2+}$) to 78%, 98 %, and 22 % for COD, colour, and ammonia, respectively, under optimal conditions.

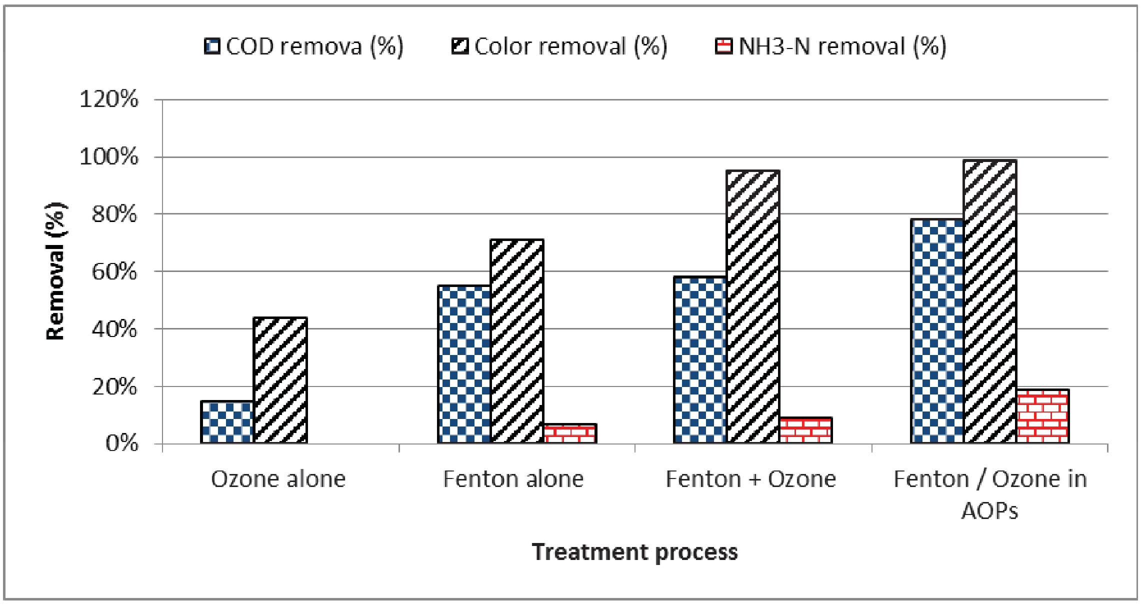

Figure 5. Comparing the performance of Fenton in advanced oxidation of ozone with other applications for the treatment of stabilized leachate.

3.2. Biodegradability

One of the major environmental problems for solid waste landfill-stabilized leachate is low in biodegradability. The performance of a system ($O_3/H_2O_2/Fe^{2+}$) in the advanced oxidation process (APOs) on biodegradability of stabilized leachate was evaluated. COD is a measure of oxidizable organic matter, whereas BOD_5 is a measure of biodegradable organic matter. The BOD_5/COD ratio is considered as a measure of biodegradability of organic matter and shows the maturity of landfill leachate, which typically decreases over time (Tchobanoglous et al. 1993; Qasim and Chiang 1994). BOD_5 measurements were performed before and after each ozonation process to assess the effect of initial COD concentration on biodegradability of stabilized leachate, and the results are presented in Figure 5. As shown in Figure 5, the BOD_5/COD ratio varied from 0.09 to 0.27. Generally, the ratio becomes higher by reducing the initial COD, especially when it is lower than 1500 mg/l. However, the highest ratio corresponds to 500 mg/l initial concentration of COD. The results in the current study proved that the system ($O_3/H_2O_2/Fe^{2+}$) in AOPs becomes more efficient in improving biodegradability in lower concentrations of semi-aerobic stabilized leachate. Several studies have exhibited improvement of biodegradability following treatment of leachate by ozone based on the AOPs. Tezaoui et al. (2007) obtained 0.7 improvement using O_3/H_2O_2. Bila et al. (2005) reported 0.3 improvements by conjunction ozone with physiochemical treatment and biological process.

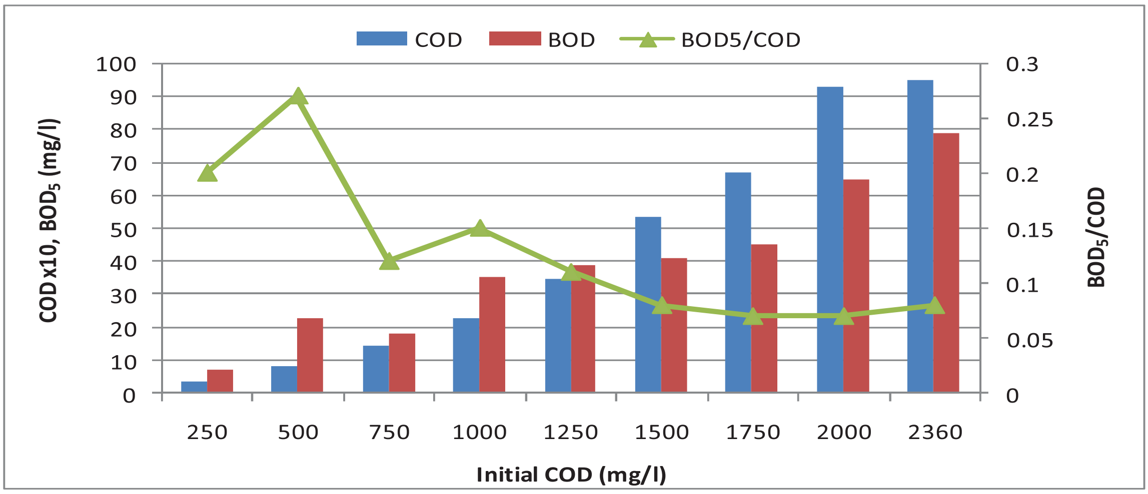

Figure 6. Effects of Initial COD on BOD_5/COD ratio in treatment of leachate by Ozone/Fenton in the advanced oxidation process.

3.2. Ozone consumption

Ozone consumption (OC) during oxidation process was calculated using Equation (6). The result is given in Table 2.

$$OC = \frac{Q_G}{V} \times \frac{\int_0^t \left(1 - \frac{C_{AG}}{C_{AG0}}\right) dt}{\left(COD_0 - COD\right)} \quad (6)$$

where QG is gas flow rate, V is sample volume, C_{AG} is off-gas ozone concentration, C_{AG0} is input ozone concentration, t is time, and COD_0 and COD correspond to the initial and final COD, respectively (Tezoui et al. 2007).

Table 2 illustrates the OC after 60 min ozonation for different initial concentrations of stabilized leachate compared with COD removal efficiency. As shown in Table 2, the lowest OC value (1.28 KgO_3/Kg COD) corresponds to 60% removal efficiency of COD. Previous studies have reported OC values. Tizaue et al. (2007) and Wang et al. (2003) reported 1.5 and 16 kgO_3/kg COD using hydrogen peroxide as advanced oxidation, whereas approximately less than 1 kgO_3/kg COD was reported by Ho et al. (1974), and Abu Amr and Aziz (2012) obtained 0.63 kgO_3/kg COD.

Table 2. Ozone consumption during ozonation of different leachate concentration by Ozone/Fenton in the advanced oxidation process.

Initial COD	**250**	**500**	**750**	**1000**	**1250**	**1500**	**1750**	**2000**	**2360**
COD	35	85	143	228	346	533	670	930	950
OC(kgO_3/kgCOD)	3.8	2.6	1.8	1.75	1.5	1.47	1.3	1.28	1.3

4. Conclusion

In the present study, the performance of system ($O_3/H_2O_2/Fe^{2+}$) in the advanced oxidation for removing COD, color, and ammonia from different concentrations of semi-aerobic stabilized leachate was investigated. The initial COD varied between 250 and 2360 mg/L, color varied between 470 Pt. Co. to 4530 Pt. Co., and NH_3-N varied between 150 mg/l to 1170 mg/l. Accordingly, the removal efficiencies varied between 60% and 87% for COD, 95% to 100% for color, and 12% to 22% for NH_3–N. Ozone consumption for COD removal was calculated, and the lowest amount of consumed ozone (1.3 KgO_3/ Kg COD) corresponded to the highest initial concentration of COD (2360 mg/L), with 60% removal of COD during 1 h ozonation. Moreover, the biodegradability (BOD_5/COD) ratio improved from 0.09 in raw leachate to 0.27 at 500 mg/L initial COD. Ozone/Fenton is an efficient method for stabilized leachate treatment and for improving biodegradability at natural pH, which suggests enhancement of the availability of applying biological treatment of leachate without pH adjustment of the effluent after ozonation.

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SIGNIFICANCE OF BOUNDARY CONDITIONS TOWARDS SUSTAINABLE HOUSING STRATEGIES: A CASE STUDY OF MYSORE, INDIA

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Abstract. *Background*: For developing nations the development of sustainable communities has to go hand in hand with the achievement of wider goals, where emphasis has to be given to the importance of lifestyle and social change. This interdisciplinary research draws understanding from the social, cultural and economic studies to define the values and aspirations of the middle class and the associated implications for sustainable housing. Middle class mores are aspirational and aim to achieve Western living standards, moving away from a traditional communitarian social model. *Methods and Results*: This research presents the results of extensive field work in the Southern-Indian city of Mysore that defines the values held by the emergent middle class in respect to the built environment. Common areas and shared spaces have traditionally been very actively used and have played a crucial role in both passive cooling strategies and the maintenance of socially sustainable communities. Fieldwork shows that attitudes to the built environment are polarised between well-maintained and protected housing interiors and poorly organised and maintained external spaces and examines how these transition spaces are used to reflect these values and concerns. Possible options for the external boundary conditions are tested by generating 3D models and applying an environmental design method, Integrated Environmental Solutions (IES). *Conclusion*: The paper reflects on whether earlier traditions in sustainable building design in South Asia (Mysore) have relevance in a contemporary context and the importance of understanding the changing preferences and values of the newly affluent demographic..

Keywords: Sustainable Housing, Indian middle class, Developing countries, 3D Model simulation.

1. Background of the Study

Those nations in the developing South inevitably differ in their approaches to sustainable development (Skea and Nishioka 2008). The imperative to reduce poverty and increase economic activity means that resource use will grow to meet the legitimate aspirations of both government and society and this has to be reconciled with transnational concerns to promote sustainable strategies for the future. Economic expansion is required before the recognised process of contraction and convergence takes place in concert with the developed world. (Mayer 2004). The research engages with sustainable development in its widest sense as formulated through the Bruntland (Brundtland 1987) definition of interdependence between social, economic and environmental realms.

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The research is based on whether such assumptions still hold true for the design of housing that might appeal to the burgeoning Indian middle class. This has been achieved through two intensive periods of fieldwork to uncover the key drivers of housing development in the middle income demographic, using mapping activity, structured interviews and questionnaires with key stakeholders. These include architects, builders, developers, planners, householders and potential purchasers. The work was undertaken in Mysore, India (Figure 1). The first published stage of the research clearly reflects a shift away from climate responsive, socially inclusive, community oriented housing to a more individual, exclusive and independent housing typology (Satish et al. 2011). This paper is concerned with the second stage of the fieldwork that market tests with key stakeholders, potential sustainable design strategies that explicitly aim to meet the expectations of the middle income consumer. The methodology for construction of a series of scenario models for market testing is described as well as using simulation techniques to benchmark the models to a series of quantitative indicators.

The fast growing Indian economy has empowered an emergent middle class whose new-found economic status and affluence have a critical impact in the process of sustainable development (Fernandes 2000a, Fernandes 2000b, Singh 2009, Wessel 2004). A former class identity based on simplicity has been transformed by economic empowerment to one of affordable indulgence (Varma 1999). Consumerism has become the primary Indian value, fuelled by the influence of the West and a more pervasive media (Fernandes 2006).

In an Indian context, changes in housing procurement and design are as much a social and cultural phenomenon as a technical one. A recognition of this fact can allow insights into the effective formulation of localised, resilient and relevant sustainable housing strategies that address quantitative issues such as carbon reduction (Skea and Nishioka 2008). India's economic growth has also increased the spending power of the middle class (Fernandes 2006). Changing lifestyles and consumption patterns have clear impacts on housing (Imtiaz and Helmut 2001, Swarup 2007). Although increased affluence and consumption benefit the middle class, it also increases carbon emissions (Saavala 2003). 60% of the emissions originating from construction activities are attributed to the housing sector (Tiwari 2003).

This increase in energy consumption is not limited to ownership of more consumer goods but can also be attributed to changes in housing typologies resulting from changing expectations of homeowners. (Satish and Brennan 2010). Traditional middle income housing as studied by the authors was communally configured with a looser relationship between external and internal realms. Contemporary dwelling templates now reflect a culture of individuality that feature highly defined boundaries forcing dwelling activities into air conditioned interiors with resource and carbon implications (Satish et al. 2011).

In the case of Mysore (Figure 1), a South Indian city, traditional residential layouts were either linear with a shared party wall, or with houses distributed around an open space (Figure 2). Entry to the house was through a semi open raised platform (Jagali) (Issar 1991). These Jagalis were shaded for most of the day and used extensively for socializing and actively used as interaction areas (Ikegame 2007). Jagalis worked as an effective climate mediating transition space and there were no other boundaries to define individual territories. Materials used for construction, thick mud walls (later brick) and terracotta tile roofs were locally sourced and with small openings towards shaded areas, they were climate responsive and exhibited sustainable features in their material choice and construction details.

Figure 1. India map: Mysore location.

Shared facilities and the efficient use of semi-open outdoor spaces for much of the day also resulted in a compact building footprint. Such climatically responsive layouts and construction using locally available material are a good example of efficient sustainable development (Vandana 2008). These houses were thermally comfortable due to planning techniques which reduced solar gain and due to the use of local materials and construction details which were climate responsive and had low ecological footprints (Satish et al. 2011).

Housing design and residential layout both changed drastically after independence in 1947. It could be argued that a move from communal provision predates contemporary economic expansion and its attendant societal changes, a sense of the communal being replaced by a priority to preserve privacy. Contemporary housing designs feature large openings, a defined and fenced plot boundary (Figure 3) making each building self-contained and introspective (MUDA 2005). Roads, independent of houses, have pedestrian ways and are clearly segregated from the property of private individuals by fencing into compounds. This is supported by local planning legislation (MUDA 1996). It is an embedded expectation that buildings no longer enclose and define the open spaces and encourage outdoor activities (CITB 1987, Satish et al. 2011).

Figure 2. A typical Agrahara, Jagali typology.

Figure 3. New houses.

Altered social and cultural values have played a crucial critical role in the adoption of new housing typologies. Changed social conditions mean that people have started to associate the strengths of community living with weaknesses. For instance, shared facilities are interpreted as leading to a lack of privacy (Satish et al. 2011).

A new housing typology has been inadvertently implemented that does not reflect local climatic conditions and this has led to increased consumption of operational energy (Figure 3). As an executive engineer responsible for urban housing development recollects, until 1970 people were careful to stay close to the city centre (Fort and Palace) (respondent no.12, interviewed on 23 July 2009). To encourage residents to move away from city centre, the City Improvement Trust Board (CITB) built houses in plots and allotted some sites free of cost for those who bought houses away from the city centre (CITB 1987). This has had a direct impact on the land footprint (Figure 4). Whereas in the earlier Jagali typology, nearly thirteen square meters of land was used per person this increased to 27 square meters per person (CITB 1987). Now, middle class people prefer the plot typology and the land footprint has increased up to 43 square meters per person (MUDA 1996, MUDA 2005). Emphasis on privacy has resulted in the use of further resources to protect property. Improved financial resources coupled with changing aspirations have contributed to building bigger houses and the choice of imported materials to reflect their owners' aspirations. These have clearly increased the embodied energy of houses (Figure 4). Changing social and cultural needs have resulted in climate responsive spaces like Jagalis becoming redundant. Social activities have moved indoors coupled with large windows, increasing conductive heat gain and increased comfort expectations have resulted in use of more lighting and spot cooling, all of which has increased operational energy requirements (Figure 4).

Unsustainable development can be identified at every level. The first published stage of the research clearly reflected and summed up the unsustainable features of community living, siting, entrances, house planning, finishes and facades. Reflecting on the earlier work, the second stage of the research focuses on particular sections of the house to investigate the specific rationale for the changes, people's preferences and the implications for sustainable housing.

Housing is thereby identified as a social and cultural phenomena and this research looks at built environment sustainability from a more bottom-up perspective. The earlier research clearly indicated changes at all levels but more so at the entrance point, the transition from street to main door. This area clearly demonstrates people's preferences, aspirations and changed attitudes and the impact of this on housing form. It is also impacted on by reconfigured layouts, preferences and requirements of homeowners.

The research focuses on this boundary condition and the second stage of the fieldwork engages with key stakeholders in examining sustainable design strategies that could also meet the expectations of the middle income consumer.

2. Boundary condition and its implication on sustainable housing

It has been argued that the pre-industrial architecture of India served the physical and spiritual needs of the populace well. At a physical level, it demonstrated an understanding of the local climate, available materials and construction techniques. Indian architect B.V. Doshi has argued that "at the spiritual level, the built-form conveyed total harmony with the regional lifestyle in all its daily as well as seasonal rituals, unifying the socio-cultural and religious aspirations of the individual and the community" (Ameen 1997).

Closer inspection reveals that the key change has been the way the house boundary is defined and the values and changes taking place at this interface. As practising architect-planner Charles Correa (1991) has argued, the climatic conditions of most Indian cities allows for the use of open and semi open spaces for interaction, gatherings and other social activities (Correa 1991). Correa identified specific Indian conditions, which aid sustainability. The use of natural light for most of the day and very minimal construction, which reduces embodied energy. He has identified (Correa 1991) four major elements as:

1. Internal private spaces
2. Area of inmate contact (the front door step)
3. Neighbourhood meeting places
4. Principal urban area

In a traditional Indian context, these spaces will always have very high usability coefficients due to the nature and way in which these spaces are used (Correa 1983). Though the notion of threshold is a theoretical construct used in sociology, anthropology, and architecture, primarily in a Western context, it is none the less relevant in interrogating modern urban conditions in India.

The research is thus focussed on these boundary conditions as they may reflect fundamental changes since Correa's writing about threshold. Although relevant in 1990, such has been the change in society that a virtuous link between building form, bioclimatic response and social structures in the household may be broken. We therefore examine whether contemporary expectations regarding security and privacy have anything to offer sustainable design strategies and if any of the more traditional approaches to threshold and form can be incorporated in the design of new housing.

3. Models and simulation analysis

The research aimed to use the observations and conclusions of the earlier research and fieldwork to identify the needs and wants of middle class homeowners. Structured interviews and surveys clearly indicated concerns regarding security and the notion of protecting one's boundary, coupled with the need for privacy, and the use of form and façade to provide visual cues in expressing wealth and aspiration (Glendinning 2011, Satish et al. 2011).

The results of the fieldwork were then triangulated with literature studies and the outcomes related to boundary conditions were used to produce different computer models, representing alternatives for major elements, a sustainability agenda and middle class aspirations. Feedback from architect, builder, and homeowner was used to define these models, which are then related to sustainable values.

The fieldwork was combined with intensive literature reviews of both contemporary Indian building typologies (Annapurna 1999, MUDA 2008, Shirley 2008, Tiwari 2001) and research on boundary, threshold and border that help explain contemporary preoccupations with security and defensible space (Blaisse 2009, Georges 2005, Georges 2008, Rashid 1998, Suzanne and Lennard 1977). From this a series of four test models were generated for study in respect to both predictive quantitative performance and as a basis for revisiting the fieldwork. The models were organised to test housing market stakeholders' responses to a range of sustainable criteria. One model was based on a traditional bioclimatic solution that reflects past models of communal living and at the other end of the spectrum, a model representative of current private sector middle class housing was constructed. Two further models pitched somewhere between these two extremes were also designed primarily to get a finer understanding of the exact levels of privacy and social interaction that might be embraced by potential stakeholders (Figure 4).

The model prepared to reflect the prevailing typology (model 3): has an approximately 4 feet high compound between neighbouring plots. The front and rear of the plot has a minimum set back of 1 meter as required by the BDA regulations. The aspiring model (4): has a very high compound that insulates it from the external world and has extensive use of imported material and ostentatious finishes in addition to very wide openings. The earlier Agrahara typologies are represented in model 1: a raised platform in the front with small openings and use of locally available material, overlooking the street. Finally based on the feedback from the first fieldwork, a combination of climate responsive and aspirational typology (model 2) was developed (Figure 5).

	Typologies	Model 1 Jagali Typology	Model 2 Jagali + Plot	Model 3 Plot + Gate	Model 4 Plot + High Gate
					
Description	Boundary condition	A traditional bioclimatic solution that reflects past models of communal living	A representative model of a combination of traditional and current middle class housing. Demarcation of boundary with very low wall. Combination of Jagali and plot system.	A representative model of current private sector middle class housing	a representative model of aspirations and high end / upper middle class housing
	Physical	Sharing party wall either in a row or arranged around the open space	The plot is defined more as a very low hedge to retain the permeability of the Jagali typology	About four feet high compound. Clear definition of one's territory	Very high compound. Min 6 feet high. Totally cut off from the external world.
	Spatial:	Use of semi-open space for most of the time	Opportunity to use open space for informal activity	Clear demarcation of territory. Presently, the space is not used for much of the activities.	Well defined barrier segregating the inside and outside. Open space and landscape areas for personal consumption.
	Visual	House and central open space are visually connected. Kids can play and people can use the Jagali for informal gatherings/activities	Developed more to suit the prevailing plot typology. Scope for interaction among neighbours.	There is a visual connection if not physical. Owners have the option tc interact with the neighbours.	Insulated and visually cut off from the street and neighbours.
Qualitative	Communal / Social	Community oriented. Common open space and other than the rear utility area, there is no individual house open space	Scope to use open space for most of the day	Scope for informal interaction with the neighbours and street. Not much importance for the exterior open spaces and community activities	Totally cut off from the neighbours. Introverted, independent and more importance for privacy. Independent of neighbours and not involved in community activities.
	Economics / reflection	More emphasis on culture than economics (Rangoli). More functional	More functional	Combination of function and appears. Skin and compound used for demorstration of one's aspiration.	Skin and compound used for demonstration of one's aspirations
	Security	Social security, compact community and known neighbours	More importance attributed to social security	Compound used as a psychological barrier, main door with steel shutter	Compound itself acts as first level of defence. Totally grill and very high individual security.
Quantitative	land foot print	13 Smt / person	27 Smt / Person	27 Smt / Person	43 Smt / Person
	Embodied energy	Use of least embodied energy and lifecycle energy	Less embodied energy		Use of very high embodied energy and lifecycle energy
	Embodied energy	0.47 MWh / SQM	0.57 MWh / SQM	0.63 MWh / SQM	0.78 MWh / SQM
	carbon emission	0.24 t CO2 / SQM	0.29 t CO2 / SQM	0.33 t CO2 / SQM	0.40 t CO2 / SQM
	Openings	Very small, just enough light inside.	Narrow openings, enough light for the interiors	Wide openings, no relation to direction and requirements	Very wide openings. Spanning most of the wall
	Climate responsive features	Climate responsive, roof, wall, construction and materials were reflective of local climate	Jagali area is shaded and could be used for most of the day	Design is independent of climate	Highly insensitive to the climatic condition.
	source of material	Use of locally sourced materials	Emphasis on use of locally sourced materials	Combination of local and imported materials.	Use of imported materials
	Security	No/least number of materials used for security other than the regular wooden door	Steel door as additional security to the main and rear doors	Steel grill for the portico area	Entire or most of the plot is covered by a grill
Summary		Most sustainable typology	Some of the features are sustainable	Some of the features are unsustainable	Least sustainable typology

Figure 4. Analysis of different model typologies.

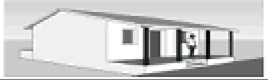
		Model 1	Model 2	Model 3	Model 4
	Typologies	Jagali Typology	Jagali + Plot	Plot + Gate	Plot + High Gate
	General description				
Volume	Different activities and their features are highlighted. Each typologies represent most desired to most prevailing and also vernacular typology.	There is no demarcation of private spaces and public areas. Sharing party wall either in a row or arranged around the open space.	The plot is defined more as a very low hedge to retain the permeability of the Jagali typology. A representative model of combination of traditional and current middle class housing.	This most prevailing model has physical barrier between street and inside plot. The height of the wall is about four feet, where the homeowners can still retain some connection with street and neighbours. Portico defines the main entrance and also acts as informal reception area of guests.	this most aspiring model has clear definition of internal and external part of individuals space. High wall, gate an elaborate portico emphasis the status of the person.
Entrance	Main relation of street and Entrance door, different activities between the two are explored.	There is a smooth transition from street to main door through semi open raised area (Jagali). Jagali is used for most part of the day.	Similar to Jagali typology entrance with additional space in the front with hedge to define ones plot area.	Direction of the opening is influenced by many factors and owners tend to locate the main door close to street and additional open space near the main door used for parking two wheel and four wheel vehicles.	Main door is recessed inside the individual property and not visible fron the street. There is no relation betwee street and main door.
Opening	Larger openings will increase conduction gain and increase cooling load. Different alternatives are worked out based on the window size and two more models are developed to examine peoples preference of overlooking shared spaces.	Very small, just enough light inside.	Narrow openings, Enough light for the interiors.	Wide openings, no relation to direction and requirements.	Very wide openings. Spanning most pa of the wall.
Security	Concern of safety and both perceived and real threat are reflected the way the boundary and openings are protected. Different level of security are represented in each model.	Social Security; compact community and new members are identified by people. Least materials used for security other than the regular wooden door.	Emphasis on social security. Steel door as additional security to the main and rear door.	Compound used as a psychological barrier and main door with steel shutter. Most of the cases steel grill for the portico area.	Compound itself acts as first level of defence. Very high individual security. entire plot or most part is covered by steel grill.
Interaction	Interaction among neighbours and home owners is the crucial part of the boundary condition. Different typologies represent degree of interaction among community.	Community oriented. Common open space. Visually connected with each other. Kids can play around and people can use the Jagali for various activity.	Scope to use open space for most part of the day. Developed more to suit the prevailing plot typology. Scope for interaction among neighbours.	Scope for interaction with the neighbours and street. There is a clear physical barrier and visual connection. Owners have the option to interact with the neighbours.	Both physically and visually cut off fror the neighbours. Importance for privacy No interaction with neighbours and no involved in community activities.
Skin	Skin used for elevation, is either construction material used as masonry or cladding for the entrance and front side of the building. The choice of material is independent of building typology. However, peoples preference of each typology is listed.	Use of locally sourced materials. Use of Mud blocks	Emphasis on use of locally sourced materials. Use of Brick and mud blocks	Combination of local and imported materials. Mostly Plastered with entrance area and street side clad with stone or Tiles	Use of imported materials. Emphasis o aesthetics and cost of the material. Extreme of use of polished granite and imported materials and also cement tiles.

Figure 5. Description of elements of different model typologies.

The models were generated with similar configuration in terms of built up area, number of rooms, size of the plot and provision for minimum light and ventilation. To focus the research more on the boundary conditions, all other components such as constructional systems and spatial planning were kept as constants. Each option was then modelled first in Google Sketch Up then exported into an environmental simulation package, Integrated Environmental Systems (IES), to predict energy consumption and carbon emissions. Longitude and latitude were specified for Mysore using hourly climate data from Bangalore, the nearest city to the study area.

Before testing stakeholders' responses to the models, the models were validated for their predictive quantitative performance by simulating them using environmental design software. IES supports a range of analytical tools for lighting, thermal comfort and resultant energy consumption and carbon emission (IES 2010). The results of the simulation for each of the four models are shown in Figures 6, 7 and 8 in respect of conductive heat gain, cooling load, peak energy demand and carbon emissions for a representative day; May 19, one of the hottest days chosen to analyse the heat gain and energy consumption due to cooling. The focus of this research is to access the implication of varied boundary condition in terms of change in energy consumption and resultant carbon emission. For the simulation purpose, only these boundary conditions of different typologies are altered while providing input in IES. For instance, the internal parameters like number of rooms, number of occupants, comfort conditions expected inside the house, minimum light, and ventilation desired are kept constant across all the models. Details like size of the openings and their location are altered among the models. Similarly, the construction materials and internal partitions are kept constant, whereas the external finish either the cladding or plastering or use of construction material as external fabric, are altered as defined in each typology. Finally, the boundary condition as either shared party wall, independent plot system, four feet compound or very high compound with high gate details are constructed and fed to IES.

IES is a dynamic simulation software which allows one to model a building by inputting form, location, meteorology, materials and building services. The simulation engine then uses real weather data to simulate models over a year in 15 minute intervals to give a relatively accurate indication of comfort and energy use (IES 2010). Since the emphasis is on social sustainability and buildings are typical middle class homes, this research does not intend to measure or compare against a benchmark or absolute standards, rather it will investigate the performance of each model on a comparison basis. In this context, IES has been a very useful tool in analysing the building performance by defining the required parameters.

IES allows the input of each typology to be altered while retaining some of the features as constant across all typologies. Further, it allows comparison of specific parameter across typologies during output. For instance the models can be run to simulate only the conductive heat gain, where the internal temperature rise is due only to heat gain by conduction. Similarly, the energy consumption due to cooling load, resultant of bringing down the internal temperature to set comfort condition is assessed (Figure 6, 7 and 8).

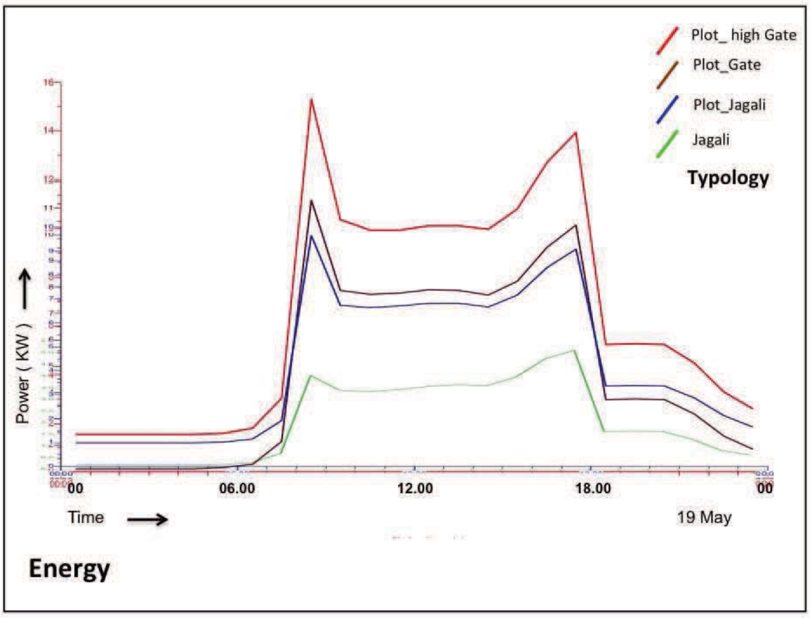


Figure 6. Energy consumption.

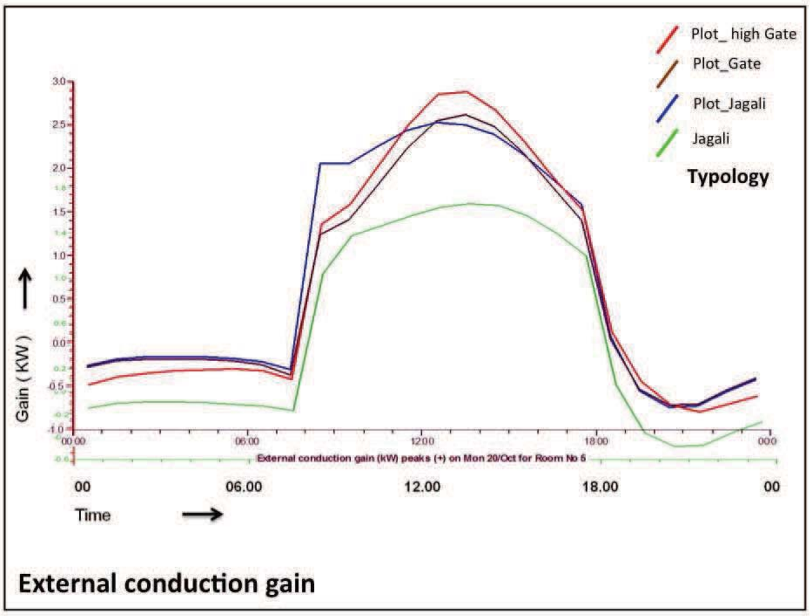


Figure 7. Conduction heat gain.

The outcome clearly indicates higher conduction gain, cooling load, energy consumption and resultant carbon emission in plot and high gate typologies and consistently lowest energy consumption and carbon emission in the Jagali typology.

A key finding is one of increased energy consumption in model 4 which represents the aspirational model. It uses nearly 65% more energy than model 1 (the Jagali typology). Similarly, there are differences in the performance of other models; for instance, in the case of energy consumption, the high compound typology (model 4) requires nearly 300% more cooling load compared to a Jagali house typology (model 1).

This will also increase the conduction gain by nearly 90%. All the results are tabulated and compared in Figure 9.

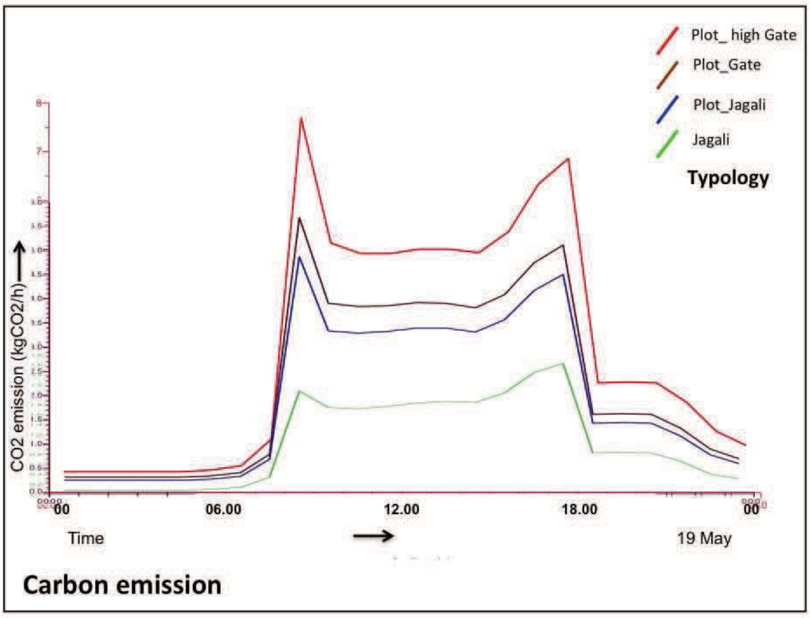


Figure 8. Carbon emission.

The simulation output demonstrates that changed boundary conditions have implications for energy consumption and resultant carbon emission. They also validate the hypothesis while developing models that explore different boundary conditions (Figure 4 and 5). It also clearly points to a direct relation between peoples' changed preferences and aspirations and the implications for energy consumption and carbon emission.

5. Field work

The main objective of achieving sustainable strategies within the existing middle class paradigm is achieved by contextualising the broad term of sustainability to Mysore condition on one hand whilst reflecting the middle class homeowners' preferences and acceptability on the other. The models and simulations reflect the local sustainability agenda and present different levels of sustainability with specific reference to boundary condition. Further fieldwork looked at the aspirations of the middle class people and their willingness to align towards more sustainable features.

With the series of scenario models complete, a second series of field work was carried out during Feb – April 2011. Here the research is more focused on testing the acceptability and preferences of homeowners by drawing on their feedback to these predefined models. The models were tested with homeowners by semi-structured interview and with key stakeholders in the design and procurement process. To analyse the issues reflected in transition spaces, elements representing middle class aspirations and the sustainability agenda were identified, namely: Volume, Entrance, Opening, Security, Interaction and Skin.

IES Simulation Result

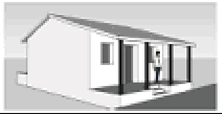
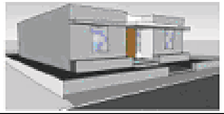
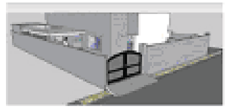
Parameters	General description	Typologies -> Model 1 Jagali Typology	Model 2 Jagali + Plot	Model 3 Plot + Gate	Model 4 Plot + High Gate
					
Energy Consumption / SMT	Energy consumed by electrical appliance are considered. To bring in uniformity, it is converted to SMT and all the models are compared to the base results of Jagali typology as 0	Bench mark	20 % of Jagali Typology	35 % of Jagali Typology	65 % of Jagali Typology
Cooling load	This simulation result accounts for the energy consumed to cool the internal spaces to comfort temperature of 23 degree.	Bench mark	100 % of Jagali Typology	200 % of Jagali Typology	300 % of Jagali Typology
conduction gain	Window size is altered in each typology and with other construction materials being constant, the simulation result reflect the conduction heat gain due to size of the opening.	Bench mark	58 % of Jagali Typology	65 % of Jagali Typology	90 % of Jagali Typology
Embodied Energy	Source of the material, energy consumed for the processing and transportation are considered to qualify the other simulation results.	Locally resourced material and construction system. Least materials imported from beyond 10 miles.	Most of the materials Locally resourced and few materials imported from beyond 10 miles.	Some of the materials Locally resourced and few materials imported from beyond 100 miles.	least of the materials Locally resourced and most of the materials imported from far distance.
Total energy consumption	it includes energy consumed due to electrical appliance, maintenance and cooling load.	Bench mark	138% of Jagali Typology	175% of Jagali Typology	275 % of Jagali Typology
Carbon emission / SMT	Total carbon emission due to energy consumed due to maintenance and cooling energy. To bring in uniformity, it is converted to SMT and all the models are compared to the base results of Jagali typology as 0	Bench mark	20 % of Jagali Typology	35 % of Jagali Typology	65 % of Jagali Typology
Summary		Most sustainable typology	Some of the features are sustainable	Some of the features are unsustainable	Least sustainable typology

Figure 9. IES simulation output.

To elicit preferences and log the choices of homeowners, architects and builders, a 'multi sorting task' methodology was followed. As Groat (1982) has argued, participants can either sort representations of buildings they have experienced directly or use pictures that function as simulations of the real environments. This research used models that were deconstructed to highlight the exact element under investigation; for instance, while asking people about their priorities regarding openings / window size and location, views showing different window conditions were derived from the original models and prepared so that the participants could reflect purely on the concerned issue and not be distracted by other elements in the images.

This technique is very helpful in this type of study as respondents are asked to place the cards in priority order from the most acceptable to least acceptable. Once noted, they are given a briefing about sustainable issues in housing and how each model and typology reflects different energy and carbon footprints. Stakeholders are asked to place the cards again in the light of their understanding of the sustainable implications of their choices. Their preferences are noted and the implications of any change in the respondents' choices are ascertained.

This multi sorting process was validated through a semi-structured interview. Apart from noting their preferences, the process was recorded and interviewees were informally questioned about their decisions.

5. Field work analysis and discussion

The outcome of this second stage of fieldwork addresses issues including social and cultural values and perception of key stakeholders towards middle-income sustainable housing. The study can be broadly addressed at two levels; firstly, it deconstructs how various stakeholders perceive boundary and threshold in housing. The interview and survey assesses the choices and preferences of a particular topology based on issues like, security, material, interaction etc. and their choice of most preferred and least preferred are further triangulated with a discussion regarding the rationale behind their choices and why they think their choice is appropriate. Triangulation of the research is thus achieved through the complementary use of literature review, semi structured interview (MST) and quantitative environmental simulation.

At second level, the study analyses how the peoples' perception changes with awareness. The homeowners were asked first to prioritise their preferences. Later after being given information on issues relating to climate change and sustainable housing, they were asked to again place their preferences. Feedback from stakeholders; architects, builders, contractors and homeowners were analysed for each element identified namely; Volume, Entrance, Opening, Security, Interaction and Materials. Though there is a clear departure from the sustainable boundary condition, the outcome clearly reflects varied preferences among different elements identified. To summarise the field work results; two representative outcomes, Volume and Opening, are discussed below.

5.1. Volume

In the case of different Volume options, stakeholders strongly feel that the prevailing plot typology is the most desirable aspect followed by the high gate typology preferred by more than 65% of homeowners. The most sustainable, Jagali typology is the least preferred option (Figure 10). According to an architect interviewed, "Privacy, dust, vibrations due to vehicle movement, forces people to build house away from road" (respondent no.111, interviewed on 11 March 2011). One builder felt that privacy is a major concern and people would not prefer to build "their house on the street without privacy" (respondent no.109, interviewed on 10 March 2011). When their attention was drawn to the well-established Jagali typology, respondents felt that there was clear deficit of trust among neighbours which is crucial for social / community living (respondent no.98, interviewed on 19 March 2011). The strong preferences of respondents are evident however while analysing these preferences it became clear that they altered significantly after they had been provided with the information regarding sustainable concerns. Homeowners' revised preferences clearly reflect a marginal decrease in the high gate typology, which is reflective of many unsustainable features and a less than 10% increase in the preferences for Jagali typology (Figure 10). Similar trends can be observed among other elements like, Entrance, and Security.

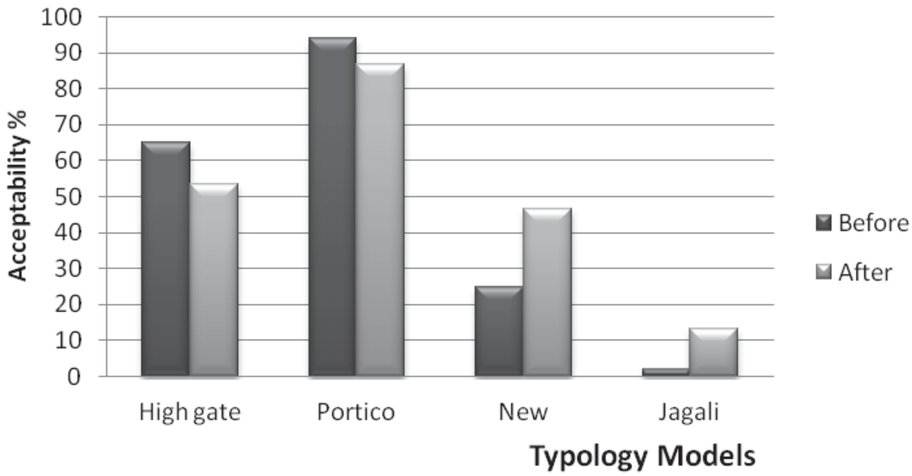


Figure 10. Volume.

5.2. Opening

In the case of different opening options, stakeholders are divided among preferences for wide, small or inward openings. Less than 10% of homeowners prefer opening towards shared areas (Figure 11). According to one architect, changed social network and priorities makes this the least feasible typology (respondent no.76, interviewed on 09 March 2011). One builder posed a more practical concern regarding flexible design and spatial organization, stating that two or four owners may have their own plans that do not correspond, and won't be successful unless they are all designed, financed and built together as a group (respondent no.115, interviewed on 13 March 2011). The concern of homeowners regarding sustainability and their willingness to adapt their choices accordingly is evident in the results. For example, after being presented with information on issues relating to climate change and sustainable housing, preferences for wide openings reduced to less than 5%, and preferences for small openings increased by 20% (Figure 11). Similar trends can be found in the case of Material choices as well.

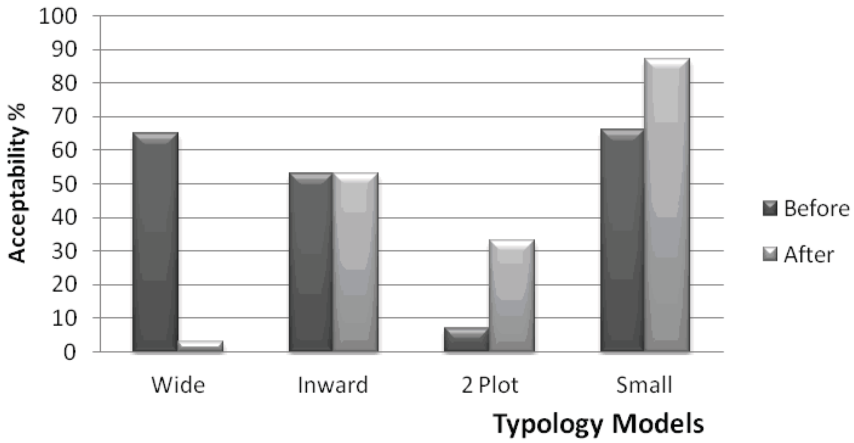


Figure 11. Opening.

Analysis of these representative elements reflects the concerns and aspirations of the middle class homeowners and also demonstrates variation in their preferences among different elements. The understanding of homeowners' perceptions and expectations enables the production of sustainable strategies, which work within an existing middle class paradigm. The outcome of the fieldwork could be summarised based on the level of acceptance of sustainable models and probability of aligning towards Sustainable Housing (Table 1).

Table 1. Summary of field work outcome.

Field Work Reflections		
	Level of acceptance of sustainable models	**Probability of aligning towards Sustainable Housing**
Volume	Least	Negative
Entrance	Least	Negative
Openings	Most	Positive
Interaction	Moderate	Perhaps
Security	Least	Negative
Skin	Most	Positive

Choices and preferences clearly represent the area in which we can expect people to support and adapt to sustainable features. The feedback can be classified in to three types. First, the elements where people are ready to change their preferences for the cause of sustainability, in this we can easily find the materials, skin and openings as two aspects which people are ready to align towards a sustainable agenda. There are certain elements for which they do not have very strong preferences and to some extent are ready to align themselves. In this case people might consider some adjustment but are not ready to forthrightly support a sustainability agenda.

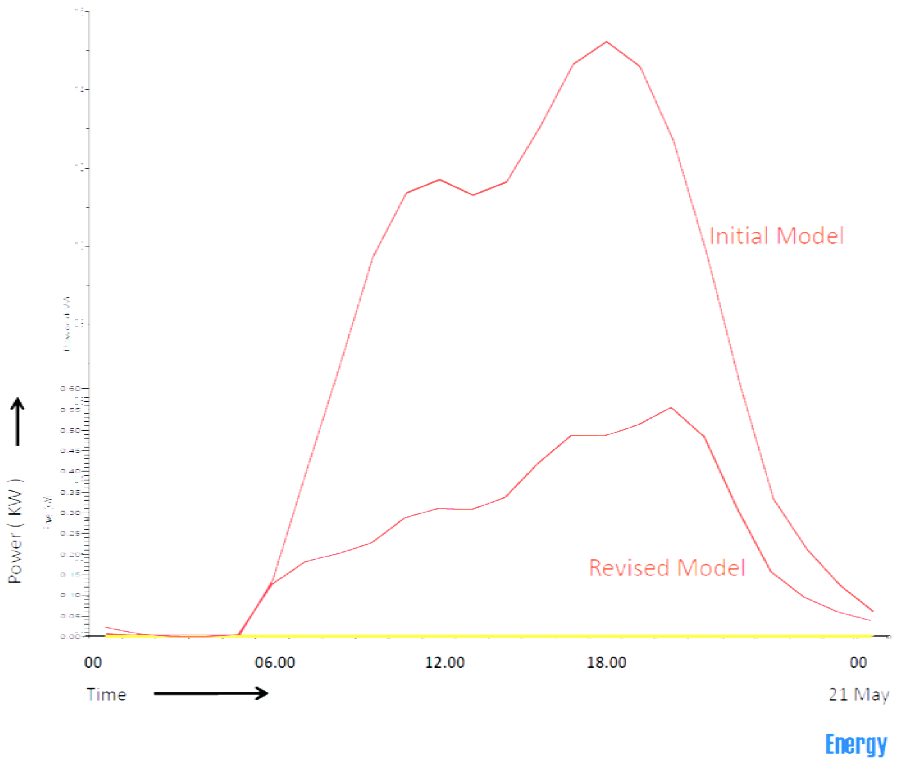


Figure 12. Post-field work: Energy consumption.

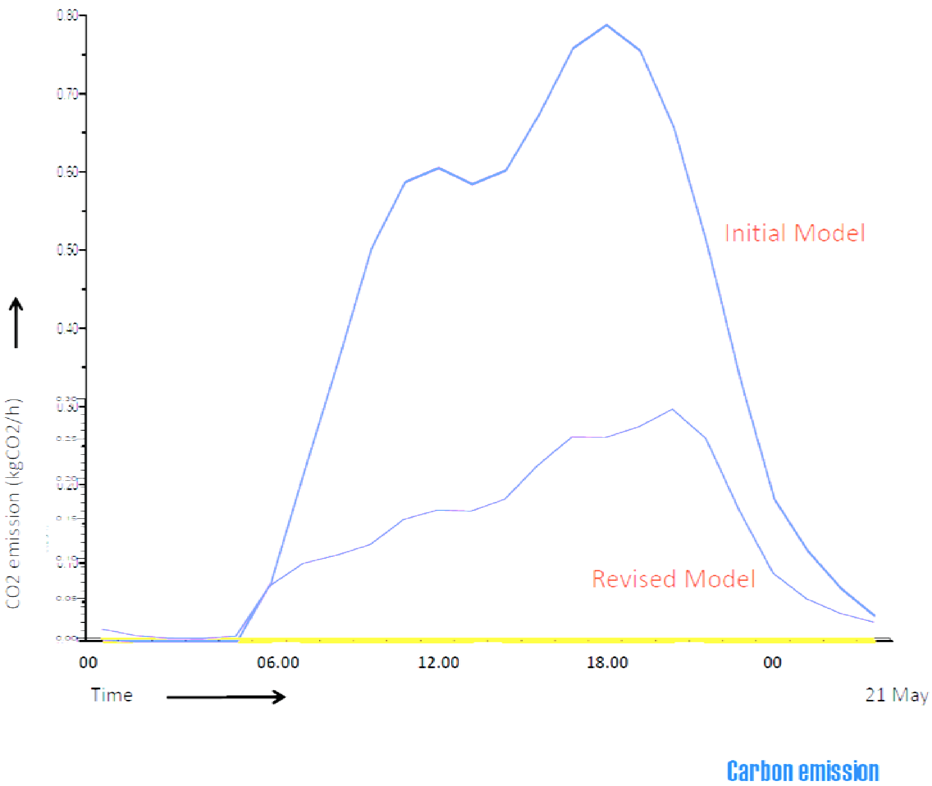


Figure 13. Post-field work: Carbon.

However when it comes to issues like security; people are not ready to compromise and would not be interested in sustainability issues and would not compromise on their perception of what is safe and secure for them. This study has been very useful in disentangling one area, the boundary condition and looking at each element within this area separately so as to identify people's choices and preferences regarding housing typology and hence the resultant sustainable concerns rather than broadly summing up the boundary conditions as unsustainable in present context.

The new IES simulation chart clearly shows a drop in the energy consumption of 40% and thus a reduction in carbon emission. The changed window parameter has also reduced the conductive heat gain by 20%. The results clearly show that, by changing the elements which people are ready to alter, we can reduce carbon emission by a fifth. This is significant because it is useful to know where we can really target and reduce emissions.

This study is also helpful in identifying the areas and elements where it is easier to achieve higher sustainable goals compared to areas where there will be higher resistance to change. Revising the model to suit both peoples' choices and the sustainable agenda further tests this. Peoples' choices and preferences, collected by social methods, were fed into the IES simulation model to analyse the difference in the process of sustainable housing. To test this one model is altered to have optimum size windows which people would be ready to align with to achieve more sustainable housing.

6. Conclusion

This study using survey field work and model simulations has highlighted the relatively recent shift in attitudes and cultural values relating to housing in Mysore India; from an inherently sustainable approach which valued shared spaces, local materials and communal activities, to one which reflects a move towards a twentieth century Western approach; of individualism, nuclear families and consumer driven values. The study also clearly demonstrates that there are elements of sustainable design like materials and openings, which people are willing to align themselves with and that there are other elements such as security, on which they would not compromise. Their immediate concerns regarding security for example would be of greater importance than the global issues of carbon emission and sustainable housing.

The results from this research highlight these particular points:

This study has explored the people's attitudes and their implication for housing in India, particularly the people of Mysore. There are however specific factors, which are unique to Mysore. For instance, although the aspiration to own a house is an Indian phenomena, middle class homeowners in Mysore are particularly desirous of owning a plot and identifying their own territory.

Though there is a clear move away from sustainable living, the values of people can be recognised as being more than 40% ready to change their life style to align themselves towards more sustainable housing.

In the process of achieving more sustainable housing there are factors like security where the perception of the owners plays a crucial role. Though homeowners are sympathetic to sustainable concerns, their fear and psychological concerns with regard to security and other issues like unorganised exterior spaces, stray animals and perceived lack of moral values in society has prompted the middle class homeowners to define and identify their territory, and protect and insulate their boundaries.

Finally the revised IES simulations demonstrates that nearly 40% energy savings and carbon reduction could be achieved without altering peoples' preferences. Further reduction requires intervention at higher level; for instance to change the entrance and setbacks which are now prevalent. To achieve this regulations and legislation will have to be reworked. On the other hand concerns about security can only be addressed at regional and policy levels.

We have to acknowledge the need for people to express and accommodate their desire for upward mobility against a backdrop of complex class and caste structure on one hand and consumerist driven influences of the media and the West.

India has identified housing as one of the eight national missions to reduce carbon emission as part of its commitment to reduce the vulnerability of the people to the impacts of climate change (NAPCC 2008), this bottom-up approach to identify the sustainable strategies acknowledging people's needs and aspirations should be a useful contribution to achieving carbon reduction and sustainable housing.

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Eliciting Inter-Temporal Value Trade-Offs: A Deliberative Multi-Criteria Analysis of Vietnam's Bai Tu Long National Park Management Scenarios

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Abstract. *Background*: While different notions of sustainability and sustainable development have been adopted in the key policy goals of agencies at multiple governance levels, initial enchantment with sustainable development as a "win-win" panacea has given way to the emerging notion of "hard choices" and "difficult trade-offs" that entail inter-generational allocation of environmental resources. Two hypotheses are explored: (i) ***Negative Discounting Hypothesis***: Hyperbolic discounting and positive discount rates do not accurately describe the decision behavior of policy actors in all natural resource management contexts; rather, negative discount rates for ecological and natural resource conservation values could also be observed in some management contexts. (ii) ***Value Pluralism Hypothesis***: Ecological, social, political and other values could be accorded higher weights than economic values in some natural resource management contexts.
Materials and Methods: A deliberative multi-criteria analysis (DMCA) model for eliciting trade-offs among values across multiple space-time scales is presented in the management context of Vietnam's Bai Tu Long National Park (BTLNP). Five management scenarios for BTLNP – business-as-usual, total conservation, total development, multi-use, and community-owned – are evaluated on six criteria: economic welfare, social welfare, good governance, ecosystem services and biodiversity protection, price of land and accessibility.
Results: After group discussions, Vietnamese participants revealed negative discounting for economic welfare, social welfare, and ecosystem services, while positive discounting for the other three criteria. Economic welfare is accorded relatively lesser weight than ecosystem services and good governance.
Conclusions: Deliberative process reveals that multiple use area and community ownership management scenarios could better serve pluralistic stakeholder values.

Keywords: Economic development, Sustainable development, Participatory decision-making, Multi-criteria decision analysis, Environmental planning, Inter-temporal trade-offs

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1. Introduction

Since WCED (1987) conceptualized sustainable development as development that meets the needs of the **present** without compromising the ability of the **future** generations to meet their own needs, almost all definitions of sustainability implicitly or explicitly address issues of inter-generational allocation of environmental resources (Norton 2005, Zia 2013). Allocation of different kinds of natural capital over time, for example, signifies **inter-temporal** resource allocation decisions that will directly affect inter-generational environmental sustainability. While different notions of sustainability and sustainable development have been adopted in the key policy goals of different international agencies (e.g. UN, IUCN), national governments, and NGOs since WCED (1987), initial enchantment with sustainable development as a "win-win" panacea has given way to the emerging notion of "hard choices" and "difficult trade-offs" that entail inter-generational allocation of environmental resources (McShane et al. 2010; Ostrom 2007).

In this paper, we focus on assessing inter-temporal value trade-offs that are inherent in sustainable management of natural resources. In particular, we focus on a specific inter-disciplinary theoretical tension that exists between two camps of sustainability theorists in operationalizing inter-temporal value trade-offs. The first camp, predominantly represented by neoclassical economic theorists and their offshoots, argue for positive discount rates in comparing the costs and benefits of inter-temporal resource allocation decisions, for example see (Becker 1976; Becker 1993; Beckerman 1994; Nordhaus 1994; Solow 1993). The second camp, predominantly represented by systems analysts, decision scientists and behavioral scientists, argue for an open-ended elicitation of inter-temporal value trade-offs, which implies that decision makers could display negative, zero, positive or even non-linear discount rates on different sets of values in different decision contexts, for example see (Keeney 2002; Norton and Toman 1997; Loewenstein et al. 2003; Norton 2005; Ariely 2009).

Neo-classical economic theory frames the assessment of inter-temporal value trade-offs from the normative perspective of a discounted utility (DU) model, which was initially postulated by Samuelson (1937). The DU model posits that people have a single unitary rate of time preference that they use to discount the value of delayed/future events. Toman (1994: 400) succinctly presents the dilemma for inter-generational equity and sustainability posed by positive discounting inherent in the DU model: "The typical criterion of discounted inter-temporal welfare maximization in applied welfare economics occupies one point in the continuum of alternative justice conceptions. This criterion not only emphasizes preference satisfaction over rights; it also is highly presentist, since with any positive intergenerational discount rate the welfare of individuals living one generation in the future is scarcely relevant to current decision making. Many writers have suggested that the presentist focus of the present-value (PV) criterion implies an influence of the current generation over the circumstances of its more distant descendants that seems, at least intuitively, to be ethically questionable." Notwithstanding the presentist bias in the DU model, it is widely used in cost benefit analysis, total economic valuation and, recently, valuation of ecosystem services, for example see Freeman (2003). In essence, the DU model posits that rational human societies should discount future costs and benefits in favor of present costs and benefits.

Behavioral scientists, psychologists, and decision scientists, on the other hand, have empirically discredited the DU model (Ariely 2009; Frederick et al. 2003; Loewenstein et al. 2003). Some have proposed an alternative hyperbolic discounting model, according to which people tend to be more impatient towards trade-offs involving earlier rewards than those involving later rewards. Yet others observe that the DU model cannot be salvaged by merely assuming a different -- hyperbolic, for example, discount function. Rather, they argue, understanding inter-temporal choice behavior requires an account of several distinct motives that can vary greatly across decisions (Frederick et al. 2003).

There are significant ethical and algorithmic limitations when cross-scale value trade-offs are negotiated merely in terms of discounted utility or hyperbolic discounting models (Kelman 1981; Norton 1991, 1994; Norton and Noonan 2007; Page 1997; Sagoff 1998; Spash 2008; Spash and Vatn 2006). Instead of imposing positive discount rates through top-down environmental management and policy-making practices, behavioral, decision and system scientists argue that societal/stakeholder preferences must be elicited through a bottom-up deliberative type of processes. Further, an open-ended methodology must be deployed to elicit inter-temporal value preferences that permit decision makers to display both positive and negative (or even non-linear) discount rates for different values when deciding about "sustainable" inter-temporal consumption rates of natural and environmental resources.

Drawing on this set of theoretical issues and debates, we posit the following hypothesis that will be explored in this study:

(i) ***Negative Discounting Hypothesis:*** Hyperbolic discounting and positive discount rates do not accurately describe the decision behavior of policy actors in *all* natural resource management contexts; rather, negative discount rates for ecological and natural resource conservation values could also be observed in *some* management contexts.

Further, the measurement of trade-offs merely in terms of monetary costs and benefits may ignore other important social, ecological and political values, which are essential for context-sensitive management of natural resources but cannot be easily monetized or classified as costs and benefits (McShane et al. 2010; Norton 2005; Norton and Steinemann 2001; Spash 2008; Spash and Vatn 2006). Pluralistic values can reside both inside individuals and among individuals in societies and across societies. Drawing on this insight, we posit a second hypothesis for this study:

(ii) ***Value Pluralism Hypothesis:*** Ecological, social, political and other values could be accorded higher weights than economic values in *some* natural resource management contexts, both at present and future time scales.

In section 2, we discuss the potential of deliberative multi-criteria analysis (DMCA) as an alternative approach to conventional DU or behavioral economic models for eliciting trade-offs among values across multiple space-time scales. While there are a range of open-ended to semi-structured and structured mechanisms for eliciting multi-scaled value trade-offs, for example see (Bazzani 2005; Chung and Lee 2009; Herath 2004; Laukkanen et al. 2002; Marttunen and Hamalainen 2008; Ramanathan 2001), this study provides results from a pilot implementation of DMCA in the management context of Vietnam's Bai Tu Long National Park (BTLNP) with a limited focus on eliciting value trade-offs across multiple temporal scales. In addition to the DMCA model, section 2 also presents the specific empirical methods, including data collection procedures that were deployed in Vietnam, and the limitations of DMCA models in eliciting value trade-offs.

We chose the case-study site of Bai Tu Long National Park (BTLNP) in Vietnam to elicit inter-temporal value trade-offs and pilot-test these two hypotheses in the context of ongoing environmental management conflicts that are symptomatic of similar conflicts worldwide between prioritizing conservation versus economic development goals in management plans. While the Vietnamese government accorded it a national park status in 2001, there are increasing sets of development pressures (especially overexploitation of natural resources such as sandy worm, jelly fish, aquaculture development, tourism development, and transportation) that threaten the ecosystem integrity in BTLNP. To discuss a range of development and conservation management options that face BTLNP (among other national parks and ecosystems in Vietnam), and the consequent inter-temporal value trade-offs inherent in each of these management options, a three-day workshop was organized near the case study site in July 2009, a part of which was devoted to a test implementation of the DMCA approach. Multiple stakeholder groups representing federal and local governments, people's committees, NGOs and academia participated in the workshop, a subset of which also participated in the DMCA exercise. The empirical results from the DMCA application in Vietnam and their decision analytical implications for inter-temporal value trade-offs and ultimately sustainable environmental management are discussed in section 3, and conclusions are drawn in section 4.

2. Materials and Methods

2.1: DMCA Model

A number of studies have been published in the broader environmental management and governance arena that demonstrate the applicability of deliberative multi-criteria analysis models (Howarth and Wilson 2006; Messner et al. 2006; Renn 2006; Stagl 2006; van den Hove 2006). This body of literature has emerged in parallel to the deliberative value focused decision analytic models (Gregory and Keeney 1994; Keeney 1992; Keeney 1988, 1996; Kiker et al. 2005). Kiker et al. 2005 present a broad review of studies that involve the application of multiple criteria decision making models for environmental decision making. Major limitations of deliberative multi-criteria evaluation methods, which concerns issues such as power dynamics in groups, categorization of value hierarchies, and weight determination processes that are explained in section 2.2 in greater detail, are discussed by Hisschenemoller and Hoppe

1995; Keeney and McDaniels 1999; Pellizzoni 2001; Shim et al. 2002; and Stirling 2006.

Our DMCA model, formally presented below, has emerged in response to earlier work of Norton (2005), Norton and Noonan (2007) and Zia et al. (2011). Outlining the elements of a value pluralistic, multi-scalar theory of sustainable environmental management, Norton and Noonan (2007:672) suggested a shift in the unit of analysis to development paths or scenarios:

"Development paths are ways our community/place can develop over time and into the future. Development paths can be thought of, alternatively, as scenarios, but here scenarios are used creatively and reflectively, to explore and evaluate possible development paths according to multiple criteria and not, as in economic models, as a methodological tool to measure welfare change. Proposed policies can be understood as interventions to modify or stabilize systemic effects on community or place, and simulations can be used to explore how policy options might lead to varied scenarios. Goals can be set, not as abstract principles that demand maximization of a single index value (e.g., economic welfare) but as descriptions of favored development paths. Proposed policies, and the development paths they are modeled to shape and encourage, can then be evaluated on multiple criteria, including economic criteria (such as job creation and comparative efficiency of different institutional means to achieve improvements on key criteria), but also including longer-term impacts on ecological systems. So, we are proposing an alternative approach to evaluation of environmental change, which shifts the unit of evaluative analysis from WTP for atomized, discrete commodities, or clearly describable changes in scenarios, to development paths that can be evaluated according to impacts on multiple scales of time and space. In this way we can choose development paths to protect a range of human values, recognizing the multiple ways humans value nature."

DMCA enables elicitation of value trade-offs as a structured participatory mechanism for groups of multiple stakeholders to iteratively discuss incommensurate values and evaluate the weights on those values for choosing valuable actions. Building upon Norton and Noonan's (2007) idea of alternate development paths/scenarios, as also operationalized in Zia et al. (2011), we formally define a multi-criteria expected value function V_{ik} for i^{th} development path in a set of m development paths by k^{th} stakeholder as in equation 1:

$$V_{ik} = \sum_{j=1}^{n} w_{jk} x_{ijk} \quad \text{s.t.} \sum_{j=1}^{n} w_{jk} = 1 \qquad (1)$$

Where w_{jk} is a weighting or Trade-Off *function* for j^{th} criterion in a set of n criteria by k^{th} stakeholder; and x_{ijk} is an "outcome" or "impact" function for i^{th} alternative on j^{th} criteria as perceived by a k^{th} stakeholder in a group of K stakeholders. For an individual decision maker, the most valued development path is the one with the highest V_{ik}. The real challenge is how to integrate/aggregate V_{ik} across groups of multiple stakeholders for choosing a development path that reflects the pluralistic values of all affected stakeholders. Formally, this aggregation challenge is represented through the assignment of Ψ_k for aggregating V_{ik} to estimate the societal value V_i of i^{th} development path, as shown in equation 2:

$$V_i = \sum_{k=1}^{K} \Psi_k V_{ik} \quad s.t. \sum_{k=1}^{K} \Psi_k = 1 \qquad (2)$$

Substituting V_{ik} from (1) in (2) yields:

$$V_i = \sum_{k=1}^{K} \sum_{j=1}^{n} \Psi_k w_{jk} x_{ijk} \quad s.t. \sum_{j=1}^{n} w_{jk} = 1 \text{ and } \sum_{k=1}^{K} \Psi_k = 1 \qquad (3)$$

Table 1. Procedural heuristic of Deliberative Multi Criteria Analysis (DMCA)

Steps	Procedures
1.	Develop a group consensus on alternate scenarios/development paths
2.	Develop a group consensus on criteria (mutually exclusive and typically incommensurate)
3.	Individuals assign weights on criteria
4.	Individuals assign their perceived outcomes/impacts on a constructed scale for each alternate scenario by each criterion
5.	Individuals participate in small group discussion to develop consensus on weights and perceived outcomes/impacts
6.	Workshop level weights and perceived outcomes/impacts are developed
7.	Workshop level weights and perceived outcomes/impacts are used as inputs to compute expected value for each scenario (as per equation 3) for evaluating alternate scenarios
8.	The valuation process is repeated iteratively with different set of stakeholder representatives

Equation 3 provides one of the many possible MCA methods to assign multi-criteria values on alternate development paths conditional upon the weights assigned to different stakeholders, the weights assigned by each stakeholder on different values in the system as well as the impacts perceived by different stakeholders for each alternate development path vis-à-vis each value in the system. Here, we formally stipulate that a *process* issue in aggregation refers to how a stakeholder is included or excluded from the set of K stakeholders. Furthermore, we define that a *power* issue in aggregation refers to the problem of assigning Ψ_k weights to a k^{th} stakeholder. In a perfectly egalitarian society, Ψ_k will be equal for all stakeholders, which is rarely the case in real societies. Power asymmetries can be explicitly represented through the asymmetric assignment of Ψ_k. Since formal MCA cannot endogenously determine K and Ψ_k, we propose the deployment of deliberative and softer version of MCA applications. In particular, we propose a continuous and iterative application of an open ended 8-step deliberative procedure, which is shown in Table 1, to estimate multi-criteria value functions for alternate development paths, as estimated in equation (3). The proposed procedure is sensitive to stakeholder selection, which is a critical feature of understanding the process and power aspects of eliciting trade-offs. Who is brought into the process at the start is important, as well as their ability to express their views during the process, e.g. are participants selected representative of the full range of interests being considered. Iterative implementation of DMCA with different stakeholder groups in specific policy settings could potentially overcome some of the sensitivities associated with stakeholder selection processes. In this paper, we demonstrate the application of this deliberative methodology in the specific context of eliciting inter-temporal value trade-offs for the management of BTLNP, Vietnam.

2.2. Limitations of DMCA Models in Eliciting Value Trade-Offs

The deliberative MCDA approach is designed to work best when processes achieve or approach "ideal speech situations" (Habermas 1984, 1998). In real world situations, however, we are far from ideal speech situations. For example, ideal speech situations require that all participants be given a fair opportunity to participate and deliberate about their concerns in any given problematic situation. In real world situations, powerful participants may use explicit or implicit forms of power to influence the participation or the position of weaker participants.

Deliberative MCDA methodologies also require extensive computational and cognitive skills to be implemented by the participants for "authentic" deliberations. In reality, as has been extensively demonstrated in decision theoretical research, many participants could be averse to forcing themselves out of their "comfort zones" or "routines" in terms of thinking about assigning constant-sum weights to values or comparing the impacts of different design options vis-à-vis different values. Another problem, known widely since the work of Howard Raifa (1968), concerns the assumption that values be mutually exclusive for assigning constant-sum weights. While decision theorists have designed very sophisticated value mapping methods to implement the requirements of this value exclusivity assumption, it is very challenging and linguistically daunting to map exclusive values. When it comes to working across linguistic and cultural boundaries, such as the case of working in Asia, this kind of exclusive value enunciation challenge becomes even more intractable due to the politics of language and other power and process dynamic issues discussed above. Messner (2006: 164) summed up methodological problems with deliberative MCA approaches: "what MCA method and which participatory approach should be selected for a certain evaluation problem? Who should determine the criteria? How is double counting prevented? Who decides on the weightings? Who is to be included in the participation process? How can objective results be attained?"

Finally, aggregation issues, i.e. who should be assigned how much weight when aggregating value functions in a given problem solving situation, have posed difficult challenges for participatory and deliberative MCA tools, as also discussed by Wilson and Howarth (2002), Howarth and Wilson (2006) and Stirling (2006). All of these are very tangible limitations of deliberative MCA methodologies and utmost attention and caution must be observed while implementing such methods in the field settings and interpreting the data from these deliberations for policy analytical purposes. For additional thorough discussion of deliberative MCDA limitations, readers are referred to Hisschenemoller and Hoppe 1995; Pellizzoni 2001; Shim et al. 2002; Stirling 2006; and Wittmer et al. 2006.

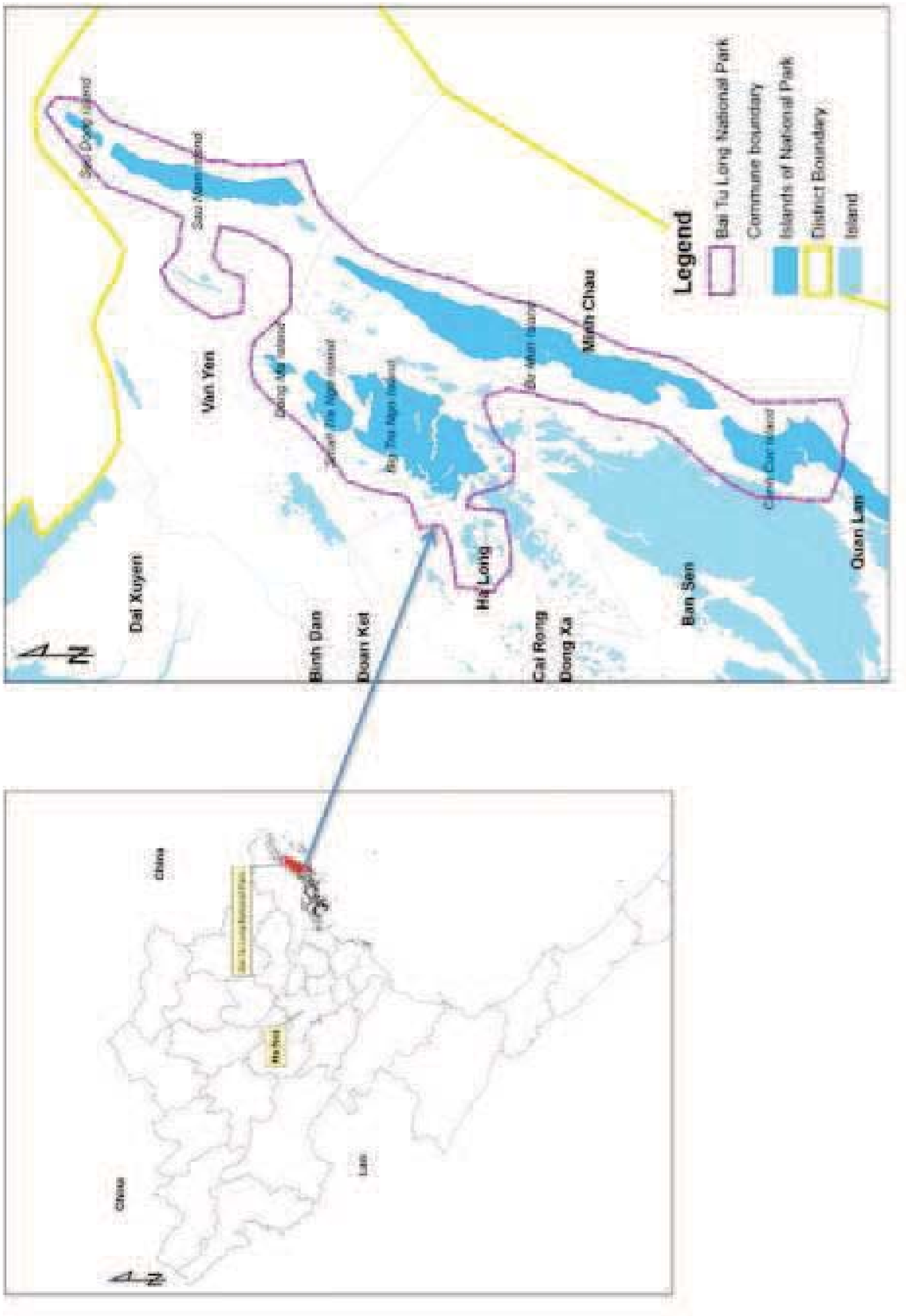

Figure 1. Location of Bai Tu Long National Park in Vietnam

2.3. Data Collection Procedures in Vietnam

A 3-day research workshop was organized in Ha Long Bay, Vietnam in July, 2009 to discuss various methodological and substantive issues pertaining to trade-offs between conservation and development issues prevailing in Vietnam. The DMCA model was implemented with 26 workshop participants during a four-hour session in the workshop. The participants included national and commune level policy makers, international stakeholders from IUCN and WWF, as well as social and ecological scientists and community scale activists. The 19 of these 26 participants completed individual level steps (as shown in table 1), while the other 7 participants did not furnish completed surveys.

To contextualize the DMCA discussion for BTLNP, the moderators (two of the authors) began the discussion by focusing upon different management and design alternatives for managing various socio-economic and ecological problems of the case study site (step 1 in Table 1). All the workshop participants have direct experience working on various conservation and development issues pertaining to the management of BTLNP. A background working paper providing detailed history and the evolution of "business as usual" (BAU) scenario in BTLNP was circulated among the workshop participants prior to the workshop. Here is a brief synopsis of this business as usual management scenario.

Bai Tu Long national park consists of over 40 islands and the bay in which they are contained [Figure 1]. It is linked to the well known Ha Long Bay, a UNESCO World Heritage Site. Bai Tu Long National Park was established in 2001 by Vietnam's Prime Minister, succeeding the former Ba Mun National Conservation Zone. The park is located within the boundaries of 3 communes: Minh Chau, Van Yen and Ha Long of Van Don. The park has a total area of 15,783 hectares, of which the marine area spreads over 9,658 hectares. The buffer zone of the park, which contains almost 25,000 people, consists of 16,534 hectares spread over 5 communes: Van Yen, Minh Chau, Ha Long, Ban Sen and Quan Lan.

Bai Tu Long national park has a variety of ecosystems and landscape types, including rocky and earthy mountains, mangrove forests, small islands, caves, natural pools, and beaches. Under the business as usual scenario, a number of species, including the rhesus monkey, the Asian Serow, the Tokay Gecko, the civet and various orchids are threatened by overexploitation of forest products on rocky and earth mountains, and are becoming rare. In addition, a number of valuable sea products including sandy worm, marine crab, *Babylonia areolata,* and sea worms are being overexploited. Intensive operation of cargo ships and fishing boats in the bay area and near the shoreline, as well as fishing by mines, threaten the habitat and egg-laying areas of sea turtles, a species that needs strict protection.

An important conflict under the BAU scenario concerns the compensation to local communities whose livelihoods have been affected since BTLNP has been set up, which may underlie some of the problems in implementing the protections afforded by the National Park status. To implement its conservation requirements, Bai Tu Long National Park authorities do not allow households/local communities to continue to harvest productive plantation forests or make use of the tourism potential of coastal protected plantation forests. While the National Park is drafting a plan to compensate the households/local communities for withholding these livelihood activities, the compensation thus far has not been paid.

A related conflict surrounding the conservation of the habitat that is the breeding place of the globally-protected turtles also reflects the tension between conservation and development under the BAU management scenario. For the local communities, the value of the ecosystem is higher if it provides them sources of livelihood. On the other hand, many domestic and foreign conservation projects, which aimed at raising awareness and promoting sustainable harvest of marine resources, have been ineffective. Our field research indicates that most of these projects have either given up mid-way or ended earlier than the initial plan. Both the governmental and non-governmental organizations, among others, have implemented several integrated conservation and development projects. However, these integrated projects have not been successful due to the low investment and inappropriate support to the local people in terms of providing them with alternative livelihoods, some of which involved pig raising, canarium plantation, and raising sweet snails (*Babylonia areolata)* to reduce pressure on harvesting sandy worm.

During the opening discussion on implementing DMCA, the following five management scenarios for BTNLP system boundaries were almost consensually chosen for further consideration by the workshop participants. All of these five management scenarios are practically a mix of conservation-development options, but slightly different from the IUCN categorization of land-uses in biodiversity hotspots (http://www.unep-wcmc.org/protected_areas/categories/index.html):

(i) **Business As Usual (BAU)**: As described above, BTLNP is maintained as a national park with buffers around it.

(ii) **Total Conservation**: Similar to IUCN land-use category of "strict nature reserve", this scenario excludes all human activity in and around the national park boundaries.

(iii**) Total Development**: This scenario will eliminate any land-use policies that require ecosystem or biodiversity conservation and permit the market forces to drive the future land-use. None of the IUCN categories will apply under this scenario.

(iv) **Multi-use Area**s: Similar to IUCN category of "managed resource protected area", stakeholders will decide a mix of conservation and development zones within the broader boundaries of the study area.

(v) **Community-owned**: This alternative arose in the specific governance context of Vietnam. Under this scenario, national and provincial scale government entities will cede land-use decision making power to the communes residing in the study area. One participant strongly objected to the inclusion of "community-ownership" scenario as a management option because Vietnamese society does not have widespread experience with this management option. After interactive discussion, this scenario was retained as an option for further exploration.

Next (step 2 in Table 2), a group consensus was developed on the multiple criteria for evaluation of these management options. The following six criteria were consensually agreed upon:

(i) ***Economic welfare:*** Maximize Per Capita Gross Domestic Product, measured at the national scale;

(ii) ***Social Welfare:*** Maintain social equity and protect cultural heritage;
(iii) ***Good governance***: Ensure transparency and accountability in the governance system;
(iv) ***Ecosystem services and biodiversity protection***: Maximize the protection of biodiversity and ecosystem services from the landscape in the study area;
(v) ***Price of land:*** Enable market forces to determine the price of land based on its location and economic exploitation opportunities; and
(*vi)* ***Accessibility***: Maintain the accessibility of the ecosystem services generated by forests and ecosystems to the local and indigenous communities.

Since we are especially interested in scale issues pertaining to different valuation criteria, for step 3 in table 2, participants were asked to individually mull over and fill in their constant sum weights for each of these five criteria along two temporal scalar dimensions: now and future. It was explained to participants that this binary/discrete temporal bifurcation was a simplification of otherwise a continuous temporal scale and that "now" represented "short term" (days to years) while "future" represented long term (decades to centuries) temporal scale. Spatial scales were not included in this particular application due to shortage of available time, but they can be added in future applications (e.g. see Zia et al. 2011).

3. Results and Discussion

3.1. Pre- and Post-Deliberative Weights on Stakeholder Values

Two interactive survey forms, as shown in Tables 2 and 3, were distributed to the individuals for weighting and assessing their perceived impacts, respectively. In Table 2, the participants were instructed to assign higher weight (in %) to the valuation criteria that were more important to them or they cared more about and lesser weight (in %) to the criteria that they cared less about for the relevant temporal scale, with the constraint that all the weights must add up to 100%. In multi-criteria decision analytical literature, such constant sum weighting schemes are also known as fixed-point techniques. Of the 19 participants, 2 participants' individually assigned weights did not add up to 100 (a range of 95 and 130), which were rescaled to 100% for statistical analysis.

Figure 2 shows the constant sum weights that were elicited from 19 participants at the individual (panel a) and group (panel b) levels. Participants were split in five heterogeneous groups of 4 to 5 individuals, with each group assigned at least one international, one national, one local and one scientist as a stakeholder. Ecosystem services and biodiversity conservation for the future generations were most highly valued by the participants, as shown by relatively higher weights assigned to this criterion in both panels of Figure 1. Noticeably, post-deliberative weighting for the protection of ecosystem services is statistically significantly higher than the weights assigned to all other criteria, both for present and future temporal scales ($p < 0.001$). On the other hand, criteria such as economic welfare and price of land were relatively assigned lower weights. In other words, participants at both the individual and group levels are willing to trade-off economic welfare for the protection of biodiversity and ecosystem services. Noticeably, participants assigned higher weight to good governance in present times, while social welfare in future time-frame was assigned relatively higher weight.

Table 2. Weighting Matrix: respondents were asked to assign weight from 0% to 100% for each value dimension, so that the total adds up to 100%. Next, respondents were asked to split the weights for each criterion along the temporal scale. Higher weight implies more importance for that value dimension. The numbers show the means and standard deviations in () from the individual level workshop respondents (N=19).

Value Dimension	***Assign Weight (0 to 100%)***	**Temporal Scale**	***Split Weights***
Economic welfare (GDP/Capita)	19.15 (6.68)	Now	8.82 (5.23)
		Future	10.33 (7.95)
Social welfare (social equity and protection of cultural heritage)	18.87 (5.05)	Now	8.02 (4.13)
		Future	10.85 (5.58)
Good governance (transparency and accountability)	20.47 (6.75)	Now	11.25 (8.15)
		Future	9.22 (5.00)
Ecosystem services and biodiversity protection	29.95 (7.60)	Now	11.83 (6.51)
		Future	18.12 (7.45)
Price of Land	5.12 (2.86)	Now	3.07 (3.30)
		Future	2.05 (2.31)
Accessibility	6.43 (4.37)	Now	3.86 (5.55)
		Future	2.57 (2.77)
Total	**100%**		**100%**

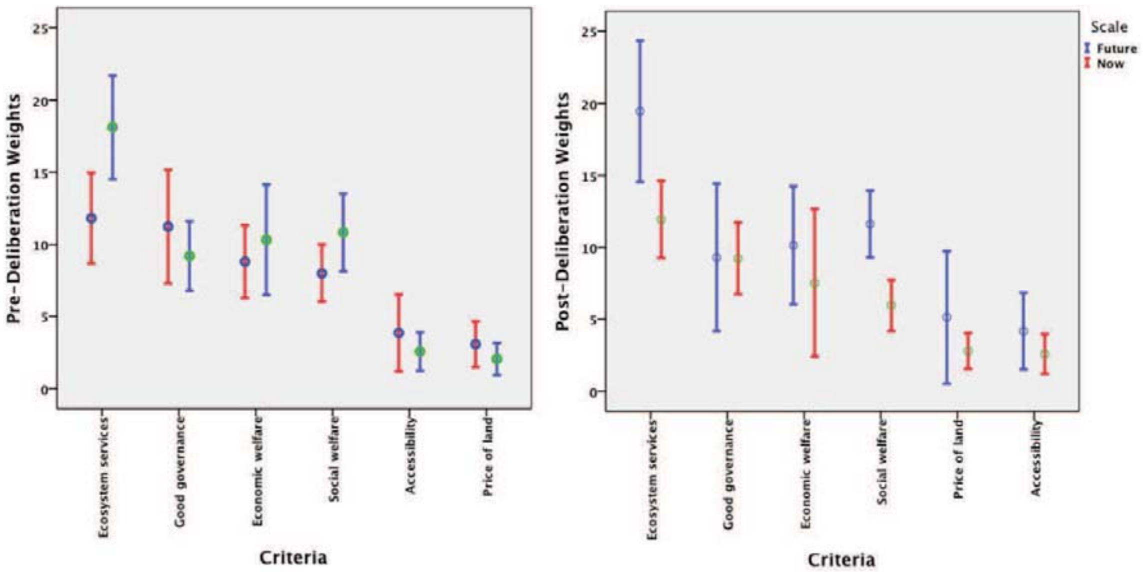

Figure 2. Pre-deliberative and post-deliberative constant-sum weights elicited for value dimensions, distributed by temporal scale: Error bars show 95% confidence interval around mean.

For assigning group-level weights, participants were allowed to keep their individually assigned survey forms (Table 2) in front of them while deliberating about developing a group consensus to assign weights. The variance in group level weights (Figure 1b) is much higher than the individual level (Figure 1a), which either shows the level of dissention among the participants within and across the groups or it is simply an artifact of small sample size (N=5 for groups). Our focus in this paper is not on providing statistically generalizable results, as this study merely demonstrates the test application of a deliberative MCA methodology to elicit stakeholder values at multiple temporal scales. More valid results will require iterative implementation of this methodology with all relevant BTLN P stakeholders, a task that could be accomplished in the follow up research. The statistical analysis reported here is for methodological demonstration purposes only. Overall, the averages of the assigned weights appear to be very similar after the deliberation.

3.2. Impacts on Values Under Alternate Management Scenarios

Table 3. Impact Evaluation Matrix: respondents were asked to assign an impact value of 0 (worst impact) to 100 (best impact) for each cell, row by row. The numbers show the means and standard deviations in () from the individual level workshop respondents (N=19).

Criteria	*Temporal Scale*	*Business as Usual*	*Total Conservation*	*Total Development*	*Multi-Use*	*Community Ownership*
Economic welfare (GDP/Capita)	Now	35.26 (23.89)	17.89 (18.95)	48.95 (30.39)	51.05 (28.99)	40.79 (23.23)
	Future	21.58 (18.11)	28.16 (25.77)	20.79 (21.93)	60.00 (24.21)	48.42 (25.98)
Social Welfare	Now	20.00 (16.24)	24.21 (22.37)	38.95 (24.86)	52.37 (25.78)	52.63 (27.45)
	Future	27.63 (25.07)	32.11 (27.35)	22.89 (19.67)	64.74 (20.98)	55.26 (33.31)
Good Governance	Now	28.05 (23.46)	25.47 (26.49)	24.58 (27.93)	52.63 (32.07)	44.74 (29.36)
	Future	29.32 (30.88)	31.74 (30.00)	23.68 (27.78)	67.37 (26.99)	49.47 (30.50)
Ecosystem Services and Biodiversity Protection	Now	29.21 (16.09)	47.11 (34.01)	30.79 (29.45)	48.16 (23.52)	38.95 (23.01)
	Future	31.05 (26.17)	60.26 (36.68)	18.16 (27.34)	65.53 (22.72)	48.16 (24.45)
Price of Land Based On its Location	Now	35.53 (30.13)	18.42 (22.36)	39.21 (37.05)	38.68 (30.99)	31.05 (27.71)
	Future	33.68 (32.01)	19.74 (25.30)	35.00 (36.17)	45.26 (34.82)	35.26 (28.74)
Accessibility	Now	20.89 (25.22)	19.47 (27.02)	15.53 (26.18)	29.47 (32.39)	23.95 (31.12)
	Future	21.32 (24.48)	20.53 (27.53)	11.58 (20.88)	33.68 (33.20)	27.89 (31.02)

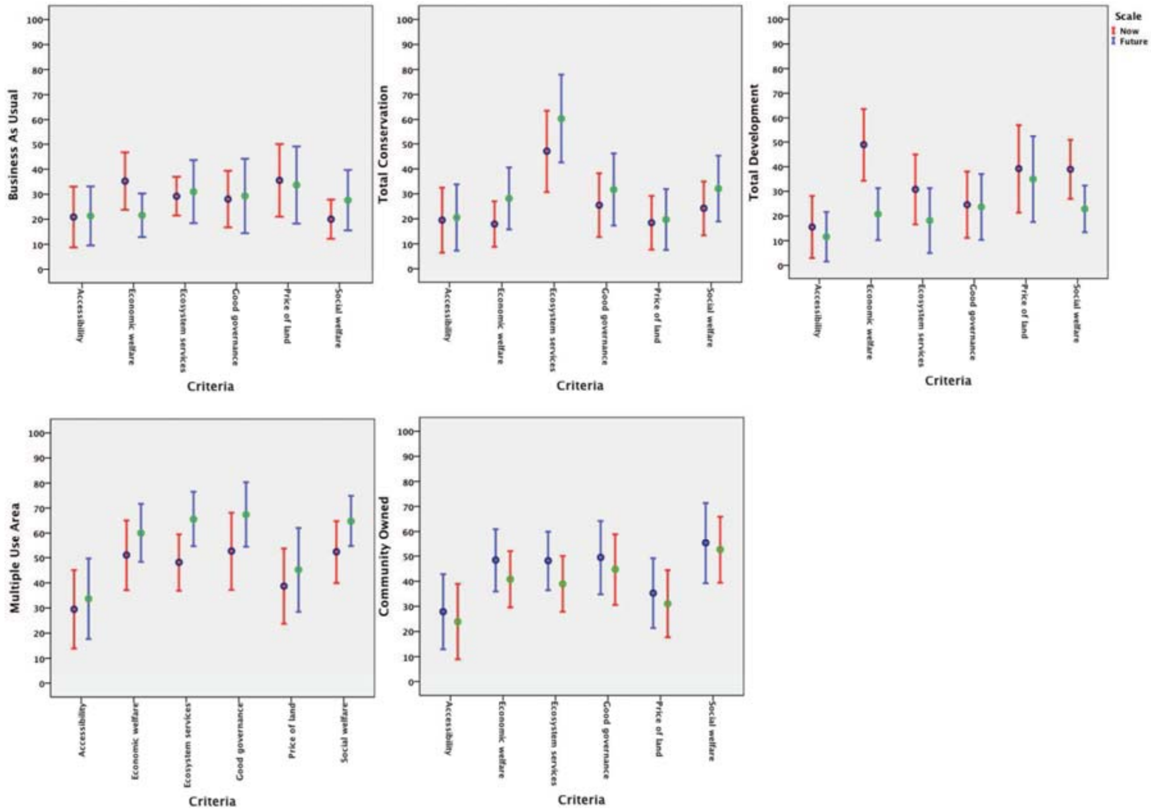

Figure 3. Pre-deliberative impacts by valuation criteria and temporal scale for business as usual (panel a), total conservation (panel b), total development (panel c), multiple use area (panel d), and community owned (panel e) management scenarios: Perceived impacts are measured on a continuous scale from 0% (worst impact) to 100% (best impact). Error bars show 95% confidence interval around mean perceived impacts.

Prior to congregating participants in groups, an impact evaluation matrix (Table 3) was also provided to the workshop participants for assigning perceived impacts on each criteria for each development path, first at individual levels; and then in deliberative groups (step 4 and 5 in Table 1). For this impact evaluation matrix, the participants were asked to assign a value of 0 (adverse impact) to 100 (best impact) for each cell (x_{ijk}), row by row of Table 3. For example, in the first top left empty cell, as explained to participants, they judged the economic welfare impact at present time scale if the business-as-usual management scenario was continued, and so on for 59 other cells in the impact evaluation matrix shown in Table 3. Figure 3 shows the impact evaluation matrices for each of the five management scenarios in five panels, as perceived by participants at the individual level prior to group deliberation. There are some interesting discernable patterns that emerge from the comparison of the five panels of Figure 3. For the management option of business as usual scenario, participants perceive relatively mediocre to worst impacts for all the criteria at both temporal scales. Consistent with the theoretical expectation, the total conservation scenario is perceived to have a better impact for the protection of biodiversity and ecosystem services at both present and especially future time scales. In contrast, the protection of biodiversity and ecosystem services, especially at future time scales, is perceived to receive much worst impact under total development scenario. The economic welfare especially at present time scale is perceived to be relatively better off under the total development scenario. While un-surprising, this finding demonstrates internal validity of the measurement constructs employed in this study. More interestingly, the management option of multiple use area is perceived to have much better impact for almost all criteria than either total development or business as usual scenarios. Similar patterns are discernable for community ownership scenario. Overall, the workshop participants appear to have a consistent perception of the impacts on the valuation criteria when different management scenarios are pursued. Larger sample size in the follow up studies will probably further narrow the confidence intervals of these perceived impacts. Group level perceived impacts (not shown here) are very similar to the individual level perceived impacts (Figure 3).

3.3. Negative Discounting Hypothesis

Regarding the negative discounting hypothesis, as shown in Table 2, we find that workshop participants displayed slight preference for negative discount rates on economic welfare: future economic welfare is weighted 10.33%, higher than present 8.82%. Similar negative discounting is preferred for social welfare (future 10.85% versus 8.02% for present), and ecosystem services and biodiversity protection (future 18.12% versus 11.83% for the present). In contrast, positive discount rates were revealed for good governance (11.25% for present versus 9.22% for future), price of land (3.07% for present versus 2.05% for the future) and accessibility (3.86% for the present versus 2.57% for the future). Post-deliberative group level weights display similar discounting functions. We thus reject the hypothesis that positive or hyberbolic discount rates are displayed by all stakeholder groups involved in natural resource management. Rather, negative discount rates, i.e. valuing future more than the present for some values, could also take place in some management contexts. Since we only used generic "present" and "future" time periods, more sophisticated time-scale is warranted in future studies to estimate discount functions.

3.4. Value Pluralism Hypothesis

For the value pluralism hypothesis, we find, as shown in Table 2, that economic welfare is only accorded 19.15% weight, while ecosystem services, good governance and social welfare values are, respectively, assigned 29.95%, 20.47% and 18.87%, weights. If workshop participants were merely concerned about economic welfare, they must have accorded it 100% weight, or at least a weight that is higher than ecosystem services and good governance. From this finding, we infer that Vietnamese stakeholders in the BTLNP management context cherish pluralistic values, which implies that those management models that require all values to be represented in terms of economic values might not be adequate in such management contexts. Conversely, multi-criteria analysis is more appropriate when we are confronted with value pluralism in management contexts.

3.5. Evaluation of Management Scenarios

Figure 4 shows the individual level (pre-deliberative) and group level (post-deliberative) expected value (as formalized in equation 3) means around their 95% confidence intervals under the assumption that each participant (or group) has equal weight (Ψ_k). We find that individual participants placed highest expected value for Multiple Use Area scenario in both pre- and post-deliberative exercises, which is closely followed by the community ownership scenario. On the other hand, the remaining three scenarios of business as usual, total development and total conservation are *dominated* by multi-use and community ownership scenarios.

Breaking down the aggregate expected values shown in Figure 4, the five panels of Figure 5 show the expected value across multiple temporal scales for each decision criterion. From the demonstrative workshop results, we find that the management scenarios of multiple use areas and community ownership provide relatively higher expected value for almost all valuation criteria in future time scales. On the other hand, the management scenarios of total development and business as usual dampen the expected values across the board. Finally, the management scenario of total conservation provides relatively higher expected value for the protection of biodiversity and ecosystem services but this scenario also dampens the expected values for good governance and social and economic welfare criteria.

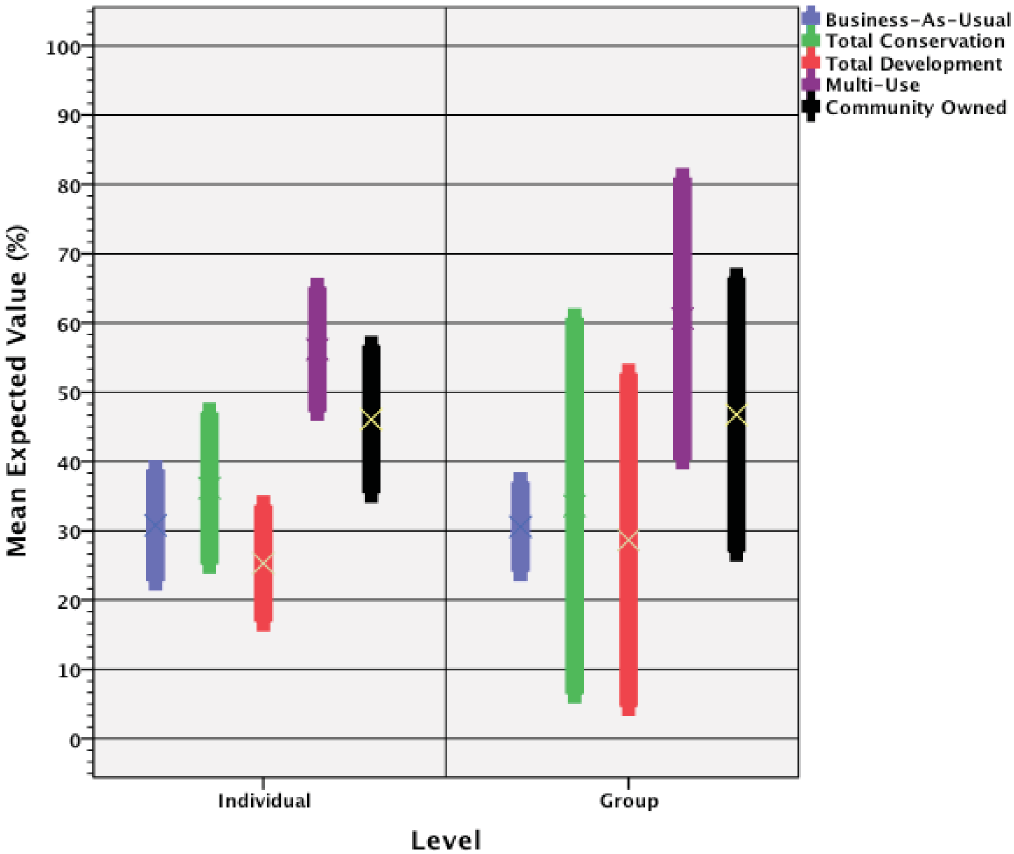

Figure 4. Expected value of alternate management scenarios, aggregated at individual (equal weights) and group (equal weights) levels.

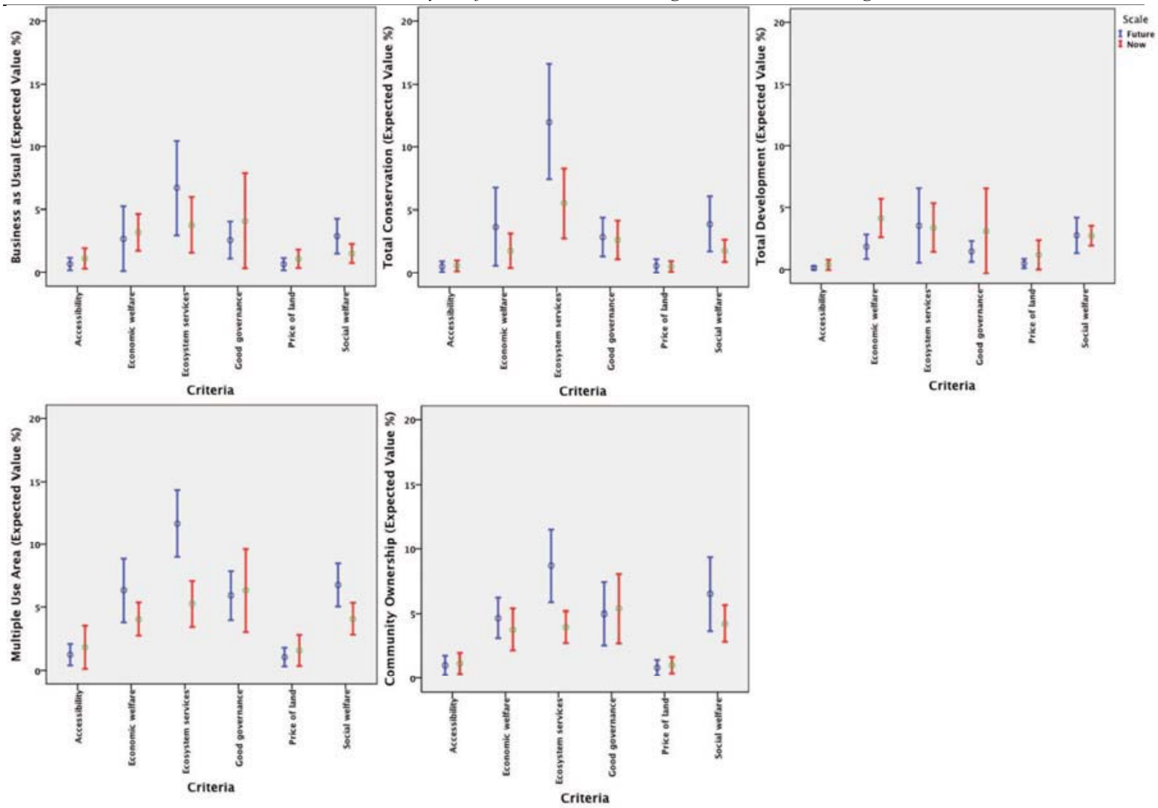

Figure 5. Pre-deliberative expected values by value dimension and temporal scale for business as usual, total conservation, total development, multiple use area, and community owned management scenarios: Expected values are measured on a continuous scale from 0% to 100%. Error bars show 95% confidence interval around mean expected values.

3.6. Implications of Power Dynamics and Governance Processes in the Study Findings

The demonstrative application of the proposed DMCA methodology for eliciting value trade-offs at multiple temporal scales shows that the business as usual management scenario at BTLNP is *dominated* by multiple use area and community ownership management scenarios at both temporal scales. The rejection of the business as usual scenario that emerged through the DMCA speaks to the power of deliberation that can be accomplished in stakeholder negotiation processes. This is despite the fact that more powerful national and international level actors were present in the group level deliberations. While this demonstrative result calls for change in the current management and more proactive research to design alternative management strategies at BTLNP, we propose iterative implementation of the proposed DMCA method in future to examine and adapt BTLNP to a relatively large number of multiple stakeholders' values. A change in the current multi-level governance system will thus be warranted. In this context, the proposed methodology could potentially provide a participatory governance mechanism for a large group of stakeholder groups to engage in structured discussions for elucidating cross-scale trade-offs. So, from the demonstrative application of this participatory methodology, we find that although workshop participants are willing to trade off present economic welfare for the long term protection of biodiversity and ecosystem services, promotion of good governance and social welfare are also considered important for both short-term and long-term time scales. Since this is a demonstrative application of our proposed DMCA methodology, we do not endorse switching BTLNP status to either multiple use or community ownership management scenarios. However, the elicitation of value trade-offs at multiple temporal scales provides sufficient information to warrant additional research with multiple stakeholders to assess the viability of current management of BTLNP and devise alternate management plans that balance multiple values.

3.7. Implications for Environmental Planning Theory and Practice

The systematic assessments of inter-temporal value trade-offs that ensue from alternate courses of public action reside at the core of sustainable environmental management (Norton 2005). A pluralistic and multi-scalar theory of sustainability must acknowledge pluralistic values across diverse cultures and societies as well as ensure that the local communities are able to participate in public decision-making. This study presented a demonstrative application of the DMCA methodology that enables both transparent participation of multiple stakeholder groups as well as elicits inter-temporal value trade-offs in variegated sustainable environmental management decision-making contexts. Following Norton and Noonan's (2007) recommendation, the focus on the unit of analysis is shifted from the atomistic assessment of expected utilities to an integrative assessment of alternative development paths across a full spectrum of values represented by multiple stakeholder groups. Similar arguments about shifting unit of analysis to development paths have been made by Vatn and Bromley (1994); Bromley (1998) and Vatn (2002). Another major finding of this study, that will require additional empirical testing, concerns the possibility of negative discount rates in environmental management and international development arenas. The discounted utility model, propounded by neo-classical economists for sustainability assessments (e.g., Becker 1976; Becker 1993; Beckerman 1994; Nordhaus 1994; Solow 1993) might not be appropriate for the environmental planning related decision making due to its fundamental assumptions about the inevitability of positive of discount rates in all management contexts. Instead, we argue that sustainability assessments, which often involve challenging decisions about current and future consumption of natural resources, must use multi-criteria and multi-scalar decision analytical models (e.g. DMCA method) to enable the articulation of negative discount rates, as evidenced in the case of BTLNP management.

The proposed DMCA procedure has direct implications for planning practice. In actual field based DMCA applications, more meaningful and detailed consideration on scenario and criteria selection must be given. This will require typically a lot more time than many stakeholders are typically willing to spend in the deliberative processes. Both the level of detail that the scenarios are described in and the decision criteria are framed may engender new conflicts or perpetuate existing tensions, as also shown by Redpath et al. (2004). Further, in practice, specific set of stakeholders engaged in the process might change the scenarios and decision criteria. In future studies, practical applications of deliberative multi-criteria and stakeholder-based approaches require meta-evaluation procedures to compare successful with non-successful interventions in the governance processes and planning practices.

4. Conclusions

We have demonstrated, from a systems analytical perspective, the viability of applying a deliberative and participatory approach to elicit pluralistic values of multiple stakeholder groups. The elicitation of value trade-offs at multiple temporal scales can also be made operational with the proposed methodology, which can be extended in future studies to include spatial scales as well. The computational and cognitive limitations of this methodology, however, pose considerable challenges. We found especially that the estimation of the perceived impact matrix proved to be computationally challenging for many workshop participants. We are optimistic that environmental impact assessment and strategic impact assessment studies can be combined with our proposed DMCA methodology to reduce the computational and cognitive stress and even incorporate uncertainty information about the impacts of alternate management options (for an example, please see Klauer et al. 2006). Nevertheless, making hard choices requires hard thinking and work in clarifying values, the weights on those values and the impacts of different management options with respect to those weighted values. Participatory deliberative mechanisms enable clarification of values, weights and alternatives and ultimately reduce the computational and cognitive stress of making hard choices. Most importantly, iterative deliberation about environmental planning conflicts will help to make value trade-offs explicit and transparent. Recognition of power and governance challenges, multiple values, multiple scales and the empowerment of local communities through deliberative mechanisms is the cornerstone of a decision/system analytical theory of environmental management that could be made operational by DMCA methodology laid out in this study in a unique environmental management context in Vietnam (given that many multi-criteria studies have been conducted in developed world). In practical applications, more thorough and concrete considerations can be given to selecting stakeholders, defining decision criteria and developing management scenarios. Finally, the discounted utility model of neoclassical economics does not appropriately capture the negative discount rates or the value pluralism harbored by many important stakeholder groups in natural resource management contexts. The presentist bias of the discounted utility model makes it inappropriate for assessing sustainable management plans. Instead, participatory and deliberative approaches that accommodate pluralistic values, and non-linear weights on those values, are more appropriate for sustainability related decision-making involving inter-generational allocation of natural resource endowments and inter-temporal value trade-offs. The proposed shift in the sustainability assessment paradigm will enable future generations to be accorded similar importance as present generations in challenging decisions often involving hard trade-offs between present and future.

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MAJOR ECONOMIES: BLACK ENERGY INTENSITY AND POLICY IMPLICATIONS

Peter Yang[1]

Abstract. This study attempted to identify common trends for the "black" economic development of the major developed and developing countries as well as exceptions to these trends. It investigated these economies' energy and carbon dependences in the last 44 years. Drawing on the traditional concept of "energy intensity," this study developed the term of "black energy intensity" to account for the intensity of fossil fuels in the total energy mix as opposed to that of renewable energy sources. Using time series of fossil fuels and nuclear power consumption, population, GDP data of 14 major economies and a combination of statistical analytical methods, it studied the trends of these economies in fossil and non-renewable fuel consumption and dependence and the related CO2 emissions individually and in groups. Based on the analysis of the group trends and exceptions of the main developed and developing economies' carbon-based energy intensities and carbon intensities, the study discussed the policy implications of these findings for these economies' future sustainable development.

Keywords: Black energy, Black energy intensity, Black energy Dependence, Oil dependence, Coal dependence, Gas dependence, Nuclear dependence, Carbon intensity

1. Introduction

Sustainable development was increasingly recognized as the only responsible way of development for the present and for the future. This important knowledge derived first from the understanding of the necessity and urgency for the mankind's action to reduce the carbon emissions of its economic activities and the resulting impact on global warming and climate change. However, this knowledge was generated from the vision that sustainable development could contribute to increasing the technological innovation for energy efficiency and renewable energy generation and consumption, and to strengthen the economy's competitive edge for sustaining its real economic growth by reducing its ecological impact on the planet (WBCSD 2000, Omer 2008, Chen et al. 2011, Garg et al. 2011, Kaygusuz 2012, Mansoor 2013).

Energy intensity (energy demand per unit of economic output), one of the most widely used indicators of energy efficiency in energy policy making and its research, has gained importance for the analysis of the economy's performance in the transition to sustainable development (Wang 2013, Anshasy and Katsaitia 2014, Samuelson 2014). This traditional concept, however, includes all energy sources, and does not distinguish between the carbon and nuclear non-renewable fuels and the renewable energy sources, making it difficult to see the changes taking place between the two groups. The use of

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this term was justified in the fossil and non-renewable fuel age, but has become more and more inconvenient in the transformative age of sustainable development, in which the accelerated deployment of renewable energy generation and consumption stand out as an urgent priority. In order to better understand this energy transformation as a process, a more differentiated methodology is needed.

To meet this research need, this study developed new terms such as "black energy intensity" drawing on the existing concept of "energy intensity," as well as various related "black energy dependences" and "carbon dependence" to account for an economy's intensity of fossil and non-renewable fuels in the total energy mix and its carbon energy reliance as opposed to its intensity of renewable energy sources to determine the degree of its transition to from the black energy generation and consumption to the green energy generation and consumption.

The major economies under investigation behaved and performed differently in this transformation, some proactively and the others reactively. Because of their economic powers in the world economy and the crucial role they have played and will continue to play in determining the direction of future globalization and climate change, their behaviors and performances have substantial economic and climate political impacts on the world economy. In other words, the major economies' moves will set the course for the further development of the globalization and climate and determine if the global economy and climate will evolve in a more sustainable way with irreversible consequences. In this sense, a focused study on their carbon intensity might shed lights on their susceptibility to oil price shocks and their competitiveness in the energy transformation.

This study attempted to explore this issue. It reviewed and analyzed the statistical data of major economies' fossil and non-renewable fuel dependence between 1969 and 2013 to see how these economies have transformed in terms of changes in their fossil and non-renewable fuel consumption, carbon emissions, and economic sizes. The major economies in this study were defined as economies with highest gross domestic outputs (GDP). The major economies involved in this study included the United States, China, India, Japan, Germany, Russia, Brazil, United Kingdom, France, Mexico, Italy, South Korea, Canada, and Spain.

More specifically, this study examined and analyzed the data of energy consumption (such as oil, gas, and coal, as well as shale gas and nuclear energy), CO2 emissions, GDP, and population from various sources. While the data of energy consumptions and CO2 emissions originated from BP Statistical Review of World Energy 2014, the population data came from the UN's World Population Prospects: The 2012 Revision, and the GDP data, adjusted to the 2005 US dollar, derived from World Bank World Development Indicators (WDI) 2014, IMF's International Financial Statistics (IFS) 2013, and International Macroeconomic Data Set, USDA Economic Research Service 2014.

Carbon dependence (Redclift 2009) is one of the defining characteristics of the existing economy since the industrial revolution, which is based on the production and consumption of carbon-based fossil fuels such as coal, oil, and natural gas. Since carbon based economic activities emit carbon dioxide (CO2) and other pollutants that were found to cause climate change and other environmental and ecological degradations (UN 1987), the investigation on the major economies' carbon dependences and the exploration of its impacts on different types of economies—the developed and the developing economies—hold the key to the energy related transformation of these economies.

Nuclear dependence is another main characteristic of the traditional economy, which is based on the production and consumption of radioactive fuels such as uranium. Nuclear energy, in contrast to carbon-based energy sources, does not emit carbon dioxide (CO2) and is seen by some as an alternative energy that could displace carbon-based fossil fuels. However, nuclear disasters caused by the Chernobyl nuclear accident in 1986 and the Fukushima nuclear accident in 2011 fundamentally questioned this view's validity, made the major economies more cautious about the development of this alternative energy, and caused some of them, especially Germany, to decide to phase out it (Sovacool 2008, Burgherr and Hirschberg 2008, Hippel 2011, Normile 2012, Revkin 2012, Hippel 2011). Therefore, examining the major economies' nuclear dependences and the implications of increasing or decreasing their nuclear dependences is equally important for the understanding of the energy related transformation of these economies.

The following sections present the results of the investigation of the changes in major economies' carbon and nuclear dependences. The term of black energy intensity includes both carbon-based and nuclear-based non-renewable fuels. It is defined in contrast to the term of green energy intensity, which includes all renewable energy sources. The term of carbon dependence used in this study is determined by two different methods. The first method looks at the share of the non-renewable fuels in the total black energy of the respective economy and the second calculated the correlation coefficient between the non-renewable fuels consumed and the GDP of the respective economy. Using this term, the major economies' oil dependences, and coal dependences, fossil and non-renewable fuel consumptions and CO2 emissions, CO2 emissions per capita, and carbon intensities are further comparatively examined.

The examination of the major economies' existing carbon and nuclear dependences is intended to help understand these economies existing strengths and weaknesses in meeting the economic and financial crises and energy related challenges of the globalized world economy and the needs for an energy transformation and related sustainable economic growth.

2. Black Energy Consumption

2.1. Total Black Energy Consumers

First, the study reviewed the total black energy consumptions of the major economies over a long period. The term "total black energy consumption" differs from the conventional term of "total primary energy consumption" in that it comprises all renewable fuels, including fossil fuels (coal, oil, gas) and non-renewable fuel (nuclear energy), but excludes all renewable energy, such as hydro, wind, and solar power, as well as biofuel. In this analysis, the data of the developed and developing economies' consumptions of carbon- and nuclear-based fossil or non-renewable fuels from 1969 to 2013 are examined.

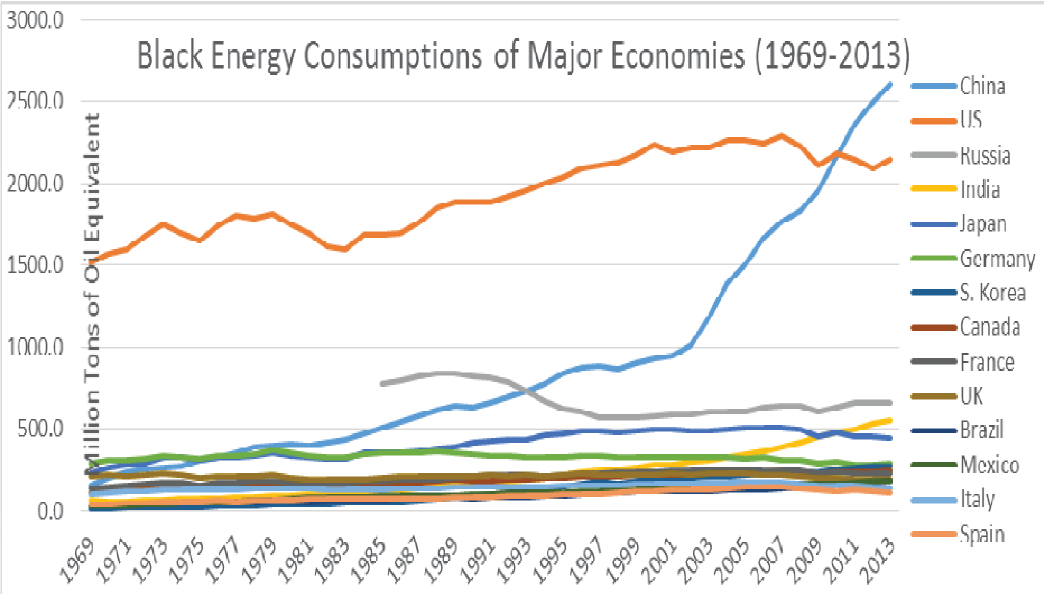

Figure 1. World's Top 14 Black Energy Consumers (1969-2013), Source: BP 2014

The comparative analysis of the world's top 14 black energy consumers found that the world's two top economies, the United States and China, stood out in their total black energy consumptions. The United States started with a top consumption level of 1516 MTOE in 1969 and grew gradually to 2146 MTOE in 2013 while China started with its black energy consumption at a modest level of 153 MTOE in 1969, which exceeded all other countries' black energy consumption levels except for the U.S. level in 1977, embarked on a steep upward trend since its accession to the World Trade Organization in 2002, and broke on its continued surge the U.S. "ceiling" in 2009. As a result, China exceeded the United States in black energy consumption by more than 21 percent in 2013.

With 2603 MTOE for China and 2146 MTOE for the United States, the world's two top economies' black energy consumptions dwarfed all other major economies' fossil and non-renewable fuel consumptions and hovered remotely over those of the next three top consumers, Russia, India and Japan, which consumed 658 MTOE, 553 MTOE and 446 MTOE of fossil and non-renewable fuel fuels in 2013.

In terms of long-term trend over the period of 44 years, most developed economies' black energy consumptions were either increased slightly (for example, approx. 90 percent in Japan and the UK, 70 percent in France, 40 percent in the United States and Italy), remained the same (such in Germany), or reduced (such as 10 percent in the United Kingdom). Exceptions to the developed countries' trend of relative high yet stable consumptions were the fossil and non-renewable fuel consumptions of Spain and South Korea, which increased by 2.2 times and 21.4 times respectively over the investigated period.

In contrast to the group trend of developed economies' relative high yet stable black energy consumptions, the black energy consumptions in most major developing countries presented a different trend, which was characterized by very low consumption levels at the beginning and dramatically increased consumption levels over the period, such as 5.4 times in Mexico, 6.6 times in Brazil, 8.3 time in India, and 16 times in China. This group trend comparison indicates a close link between the black energy consumption with the development level of an economy. While the developed economies with high-level yet low-increasing economic activities and related energy demands determined their high yet stable black energy consumptions, the emerging developing economies with initially low-level and then high-increasing economic activities and related higher energy demands determined their low yet fast increasing black energy consumptions.

The black energy consumption of Russia, a transitional economy, reduced by 20 percent in 2013 from the 1985 consumption level, which resembled more the trend of the developed country group and represented thus exception to the developing country group's trend. This outlier phenomenon of Russia's black energy consumption was mainly caused by the significantly reduced energy demand because of the more than 56 percent economic downturn in the ten years after the disintegration of the former Soviet Union and the less than 1 percent average annual growth of the real GDP in the entire 44-year period of the investigation (USDA, 2014).

The results of the comparative dynamic study of the long-term trends of the two groups' black energy consumptions showed important policy implications. First, while the developed economies demonstrated a stable or even declining black energy consumptions, their existing high black energy consumption levels cannot be expected to be reduced drastically unless they invest significantly more in renewable energy innovations. Second, the drastic increases in black energy consumption levels driven by the developing economies' catch-up developmental energy needs can easily match or exceed the decreases in the developed economies' black energy consumption levels. The combined effect of these two trends of fossil and non-renewable fuel consumptions is an aggregated increased black energy demand in the near future, which will pose significant environmental and ecological challenges to the planet and require both developmental groups to make joint efforts to speed up energy transformation and sustainable development.

2.2. Black Energy Consumption Per Capita

Next, the study reviewed the black energy consumptions per capita of the selected economies over a long period. In this analysis, the data of black energy consumption and population of the 16 major developed and developing economies from 1969 to 2011 were used. The results of the per capita analysis of the energy consumption are presented in Figure 2, which showed a reversed picture to that of the results of the previous aggregated analysis of total black energy consumptions.

First, in contrast to the estimate of a previous study by Kontorovich et al. (2014) that the per capita energy consumption was reduced by more than 40 percent in the

United States, Great Britain, and France, and by approximately 20–30 percent in Germany, Canada, Switzerland, and Japan over the last 30–35 years, this study found that the per capita black energy consumption was reduced slightly by 7.2 percent, 21.4 percent, and 3.6 percent in the United States, the United Kingdom and Germany respectively; all other developed economies displayed increased black energy consumptions, i.e. by 15.3 times in South Korea, 1.3 times in Spain, around 35 percent in France, 57 percent in Japan, 18.5 percent in Italy in the 44-year period of investigation. While the discrepancies between the findings of these two studies on the developed economies' data might be partially explained by their different scopes of data, i.e. per capita energy consumption vs. per capita black energy consumption, exploring the discrepancies would be an interesting research topic of a dedicated study.

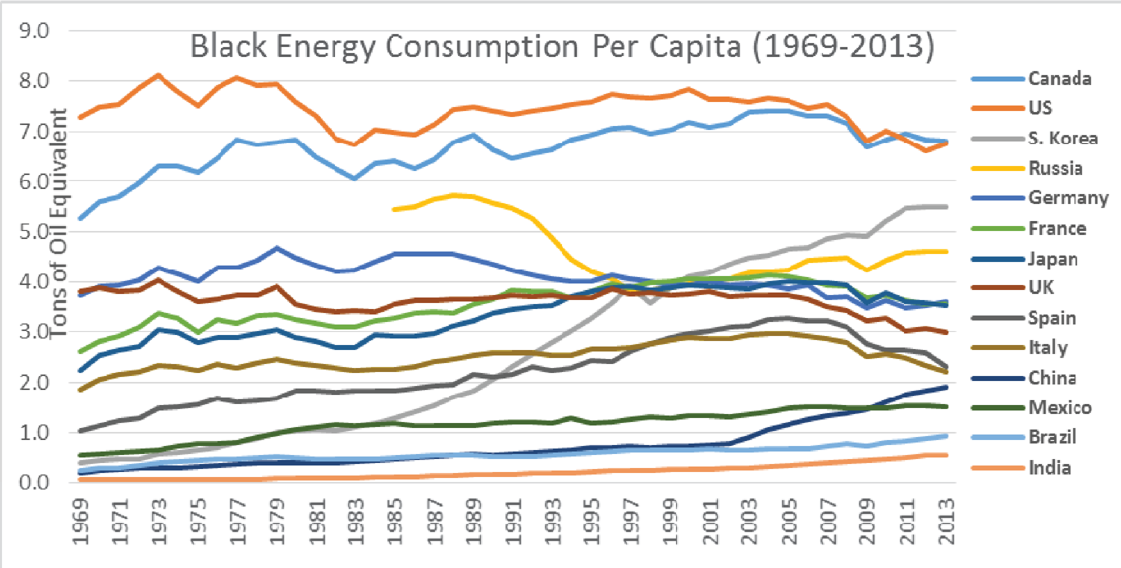

Figure 2. Black Energy Consumption per Capita of Major Economies (1969-2013)
Sources: BP 2014, Destatis 2014, NBS 2014, UNDESA 2014, WPS 2014

Second, as a group, the developing economies showed a trend of more rapidly rising black energy consumptions than the most developed economies. For example, China's increased by 8.9 times, India's by 8.3 percent, and Mexico's by 1.7 times. However, Russia's black energy consumption per capita was an exception to this trend. It started with a relatively high level in the 1980's (where its data started to become available in the compatible format) and showed a 15.3 percent decreased in 2013 from that initial level. However, it was still 1.4 times higher than China's in 2013.

Third, China was one of the four lowest black energy consumers per capita among the investigated major economies although it took the top position of this group since 2010, followed by Mexico, Brazil and India. Its black energy consumption per capita was consistently above India's in the entire period, but had an alternate position with Brazil's for a long period until 2002. That year, China's black energy consumers per capita took off from the levels of developing countries, and doubled between 2003 and 2013. As a result, it exceeded Brazil's in 2002 and Mexico's in 2009, and was poised to reach the bottom level (Italy's) of the developed economies' black energy consumptions per capita in the near future.

Fourth, all developed economies' black energy consumptions were still higher than China's in 2013. For example, Italy's were by 15.4 percent higher than China's, Spain's by 21.4 percent, UK's by 56.3 percent, Japan's by 84 percent, France's by 85.2 percent, Germany's by 88 percent, South Korea's by 1.9 times, the United States by 2.5 times and Canada's by 2.6 times higher.

Previous studies also showed that the average citizen's energy consumption was below the energy consumptions of the average citizens in developed nations and this energy consumption "inequality" was in line with the income inequality between the two groups (Duro et al. 2010, Duro and Padilla 2011a and 2011b, Andrich et al. 2013). The results of this study revealed that even if the total black energy consumptions of some developing economies caught up or even significantly exceeded those of the developed economies, the group disparity in per capita energy consumptions between the developed country group and the developing country group observed in previous studies still existed at the end of the investigated period; however, it was significantly reduced in recent years.

What stood out in this comparative study was that South Korea, a fast rising yet still smaller economy than China, Japan, and Germany, assumed the third place in black energy consumption per capita among the 14 major economies in 2000, which increased more than 13 times in this examination period, an even faster increase than that in China (8.9 times). This top rising speed of South Korea's black energy consumption per capita could be explained by a number of factors, including the initial low fossil and non-renewable fuel consumption level (0.4 TOEs vs. that at 7.6 TOEs in the United States and that at 0.2 TOEs in China), high share of energy intensive sectors in industrial energy consumption (62 percent in 2009), rising share of the main energy intensive sector, the steel making industry, since 1990 (33 percent in 2009), and rapidly rising energy demand driven by overall economic development (ABB 2011).

These findings for the sustainable economic transformation indicate that the determined yet fair global efforts of carbon reduction should not be merely based on the total amounts of black energy consumption and CO_2 emissions of an economy, but must also be based on the aggregated numbers in relation to other numbers such population sizes and GDPs. Accordingly, the global and national strategies and policies of carbon reduction and sustainable development should be informed and updated individual economies' developmental needs for energy consumption and the unequal per capita energy consumptions, which have been largely biased to the developed countries. For example, while the developed countries should primarily focus on carbon reduction, the developing countries can first focus on carbon intensity reduction, and then focus on carbon reduction when the energy disparity has reduced.

2.3. Black Energy Intensity

This section presents the findings from the analysis of energy intensity of the major economies. The term of black energy intensity was measured by dividing the total fossil fuels and nuclear energy consumed by the gross domestic product (GDP) of an economy. Accordingly, the data of total black energy consumptions and GDPs of 14 major economies from 1969 to 2013 will be examined.

Since purchase power parity (PPP) valuated GDPs can more accurately compare the long-term trends of various economies, this method was used for the years in which the PPP adjusted GDP data existed. However, since PPP-adjusted GDPs were only available for the period between 1980 and 2013 (IFM WEO, 2014), the exchange rate based real GDP data adjusted to 2005 dollar (USDA) were used for the period between 1969 and 1979. However, since 1979 was the year when China started its market-oriented reforms that dramatically impacted its energy policy, the division of the comparative analysis of black energy intensities into two different periods with the dividing year of 1979 has the unintended benefit of helping better understand the historical changes in China's black energy intensity in comparison with other major economies' in these two different periods. In the following, the results of the exchange rate-based analysis are shown in Figure 3 and those of PPP-adjusted in Figure 4.

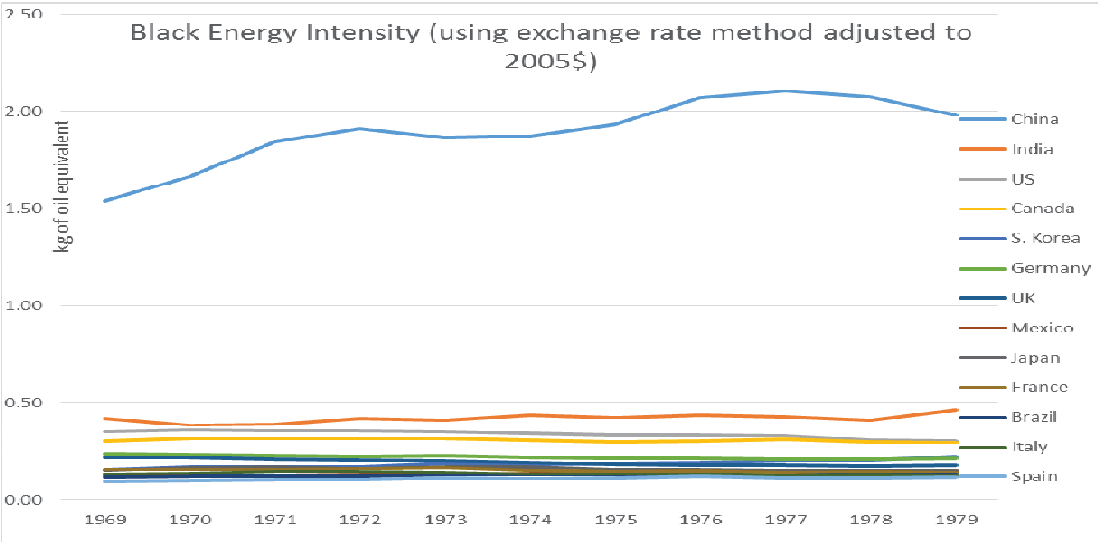

Figure 3. Foreign Exchange Based Energy Intensities of Major Economies
Data Sources: BP 2014, USDA 2014, World Bank 2014

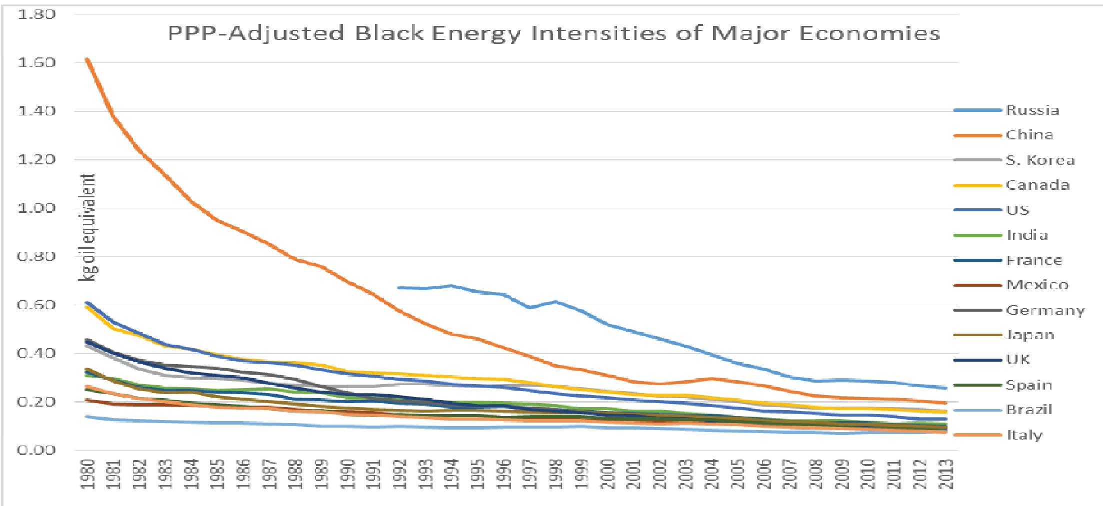

Figure 4. PPP Adjusted Black Energy Intensity of Major Economies, Data Sources: BP 2014, IMF 2014

It should be noted that Russia was not included in this analysis because of unavailability of the time series of the fossil and non-renewable fuel consumption and GDP data. The results of the exchange rate-based black energy intensity analysis reveal several insights.

First, China's black energy intensity was the highest among the 13 major economies, and much higher than all other economies' involved in this investigation, ranging from 2.7 times higher than India's to close to 15.5 times higher than Spain's in 1969 and from 3.3 times higher than India's to 15.9 times higher than Spain's in 1979.

Second, China's black energy intensity was increased by 28.4 percent during this period and, when it reached the top level in 1977—the year before China started its economic reforms, the increase in that year was by 37 percent from its initial level in 1969.

Third, China's black energy intensity increase was not a complete outlier in this period. As a matter of fact, the black energy intensities of 6 out of 13 major economies under examination experienced increases. For example, South Korea's black energy intensity increased by 39.3 percent (an even higher increase than China's), Spain's by 26 percent, Mexico's by 25.9 percent, Brazil's by 15.5 percent, and India's by 10.2 percent.

Fourth, the black energy intensities of more advanced economies were all decreased during this period; for example, the United Kingdom's decreased by 17.7 percent, the United States' by 12.8 percent, France's by 9.7, Germany's by 9.4, Italy's by 5.8 percent, Japan's by 2.9 percent, and Canada's by 2.1 percent.

Fifth, except for China's extremely high black energy intensity, there were no obvious group differences in black energy intensities that would distinguish developed countries from developing countries during this period.

It should first be noted that Russia was included in this PPP adjusted black energy intensity analysis, but because of lack of data, its time series did not cover the entire examination period, but started rather from 1992. The results of this PPP adjusted black energy intensity analysis showed some similarities to the previous exchange rate based analysis. For example, although the incomplete time series of Russia's black energy intensity made it impossible to see if Russia's black energy intensity per capita was higher than China's from the beginning of this period or even in the entire previous period, it was obvious that China continued to be one of the two top black energy intensive economies among the major economies during this examination period.

The two period black energy intensity analysis of the major economies showed that China's extraordinarily high energy intensity could be attributed to its dual historical status as both a Socialist economy (whose low black energy prices led to low black energy efficiency) like Soviet Union and a developing economy (whose low development level led to high black energy consumption) like India. The results also indicated that China's black energy intensity experienced a drastic reduction since its departure from the Socialist planned economic model and its new trajectory as a market based economy with increasing sophistication and maturity. This transitional feature of the Chinese economy explained China's exceptional reduction of energy intensity observed by earlier scholars such as Kepplinger et al. (2013).

At the same time, the comparative study revealed that as of 2013, China's black energy intensity still ranked second among the investigated major economies, only slightly below Russia's, but was still significantly higher than other major economies', ranging from 20 percent higher than South Korea's to 1.62 times higher than Italy's in 2013. This indicated that China still has to make substantial efforts to reduce its black energy intensity and improve its energy efficiency as black energy is still a central pillar of China's current energy policy.

On the other hand, the results of the recent period black energy intensity analysis also showed some distinctive trends that were not observed in the previous exchange rate based black energy intensity analysis of the earlier period.

First, as soon as China started its market based economic reforms in 1979, its black energy intensity per capita moved drastically and continuously downward, with a small rebound between 2003 and 2006. As a result, in contrast to the country's rising black energy intensity during the previous investigative period, China's black energy intensity decreased by 88 percent in 2013 from its beginning level in 1980 in the second investigative period.

Second, the decreasing black energy intensity was not a trend exclusive to China, but rather a general trend for all major economies included in this second examination period. Other developing economies' black energy intensities reduced by 64.6 percent for India, 53.2 percent for Mexico, 44.9 percent for Brazil in the period between 1980 and 2013, and 61.5 percent for Russia in the shorter period between 1991 and 2013. The developed economies, on the other hand, witnessed collectively even higher black energy intensity reductions, for example United Kingdom by 82.4 percent, Germany by 80.3 percent, the United States by 79.1 percent, Canada by 73.4 percent, Japan and Italy by 71.6 percent, France by 69.2 percent, Spain by 68.7 percent, and South Korea by 62.5 percent.

The finding that the developed economy group had a higher rate of black energy reduction than the developing economy group suggets that the black energy reduction was related to the development level, technological advancement and industrial structural change. This finding was in line with the findings of similar studies. For example, Samuelson (2014) observed that the reduction of energy intensity was faster than many policymakers realized and Voigt at al. (2014) found that except for Japan, the United States, Australia, Taiwan, Mexico and Brazil, the reduction of global energy intensity was more driven by technological change than by structural change. At the same time, South Korea's slower reduction rate of black energy intensity per capita and its current even higher black energy intensity than all major economies except for Russia and China suggests that South Korea's lower degree of industrial structure change and high economic growth played an important role in the slow pace of reducing black energy intensity.

This black energy intensity analysis has significant policy implications. It showed that developing and transition economies Russia, China, India, Mexico, and Brazil need to design and improve their policy tools to encourage innovation and technology investment in improving their black energy efficiency and further reducing their black energy intensities. At the same time, the study suggested that despite their advanced technologies, the developed economies also need to further move away from energy intensive sectors in order to more smoothly improve their energy efficiency.

2.4. Black Energy Consumption

2.4.1. Oil Dependence

First, the study examined the oil dependences of the 14 major economies and the oil dependence of the world economy as a whole. To better understand how the growths of the world economy and the individual major economies depended on oil, the study used the following two methods: a) the share of the oil consumption in the total energy mix and b) the correlation coefficient of the oil consumption with the real GDP of an economy. While the first method looked at the importance of the oil consumption in comparison with other forms of energy, the second method examined the interaction of the oil consumption with the economic growth of the individual major economies.

Using the first method, the study first looked at the share of the oil consumption in the total primary energy consumption for individual major economies and the world economy, and then compared these shares over the entire 44-year examination period.

This method examined how the individual major economies and the world economy changed their individual oil consumption in terms of their total energy consumptions annually and over the entire examination period. The results of this examination presented a more detailed and specific view of the black energy consumptions discussed in the previous section.

The examination using this method generated several findings. First, the major economies' average oil share reduced from 49 percent in 1980 to 42 percent in 1990 and to 35 percent in 2013 whereas the world economy's average oil share reduced from 45 percent in 1980 to 39 percent in 1990 and to 33 percent in 2013, a worldwide average decrease by 27 percent from 1980 to 2013 and 16 percent from 1990 to 2013. This indicates that both the major economies and the world economy presented a general downward trend in their shares of oil consumptions in total energy mixes.

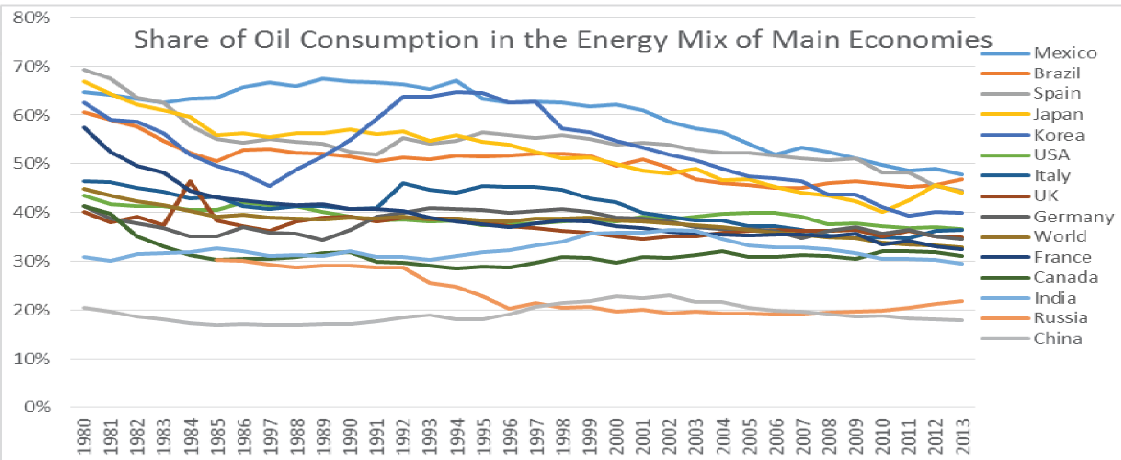

Figure 5. Oil Dependence of the Major economies: Share of Oil Consumption in Total Energy Mix

Second, the decreases of individual economies' oil shares in 2013 from 1980 ranged from 44 percent in France and 36 percent in Spain and South Korea to 13 percent in China and 5 percent in India. Interestingly, the different decrease rates of the five major economies were related with their initial levels of oil shares, with 69 percent for Spain, 63 percent for South Korea and 57 percent for France versus 31 percent for India and 20 percent for China. In other words, the three developed economies with higher initial oil shares had much bigger decreases than the two most populous developing economies with lower initial oil shares. Considering that both China's and India's oil consumptions increased 5.3 percent on average annually, the decreases in their oil shares in 2013 from 1980 and the further decreasing trend in the last five years were mainly caused by the even faster increases of their coal consumptions (5.8 percent and 5.5 percent annually).

Third, the above divergent "trends" between the three main developed economies and the two main developing economies did not, however, apply to other developing major economies under examination. For example, the top two major economies with highest oil shares in 2013 were both developing economies, i.e. Mexico (48 percent) and Brazil (47 percent), and the reductions of their oil shares (26 and 23 percent respectively) in 2013 from 1980 were also bigger than those of many developed economies, such as Germany (17 percent), the United States (16 percent), Italy (21 percent), the United Kingdom (13 percent).

Fourth, the comparison of the major economies' average annual oil shares from 1980 to 1990 with those from 1991 to 2013 revealed that while all major economies had decreasing oil shares in the first period, this downward trend stopped in India and China in the second period with slight increases in their average annual oil shares by 1 percent and 2 percent respectively over the first period, and the two major economies thus became exceptions to the trend of decreasing oil shares.

Using the second method, this study examined the relationship of the oil consumption with the economic growth. It first identified the annual changes in the real world GDP (adjusted to 2005 dollar) and the real GDPs (adjusted to 2005 dollar) of the individual major economies and the world economy and the annual changes in their oil consumptions during the period between 1980 and 1990 and during the period between 1991 and 2013 and then ran the correlation analysis between these two time series of the oil consumption and real GDP in these two periods for the major economies and the world economy. The separation of the 44 examination years into these two periods was designed to gain a better understanding of how the oil dependences of the individual major economies and the world economy based on the second method have changed between the two different periods.

The results of the investigation using the second method, which are presented in Figure 6, demonstrate that the world economy was heavily dependent of the oil consumption in the entire investigative period although its oil dependence slightly reduced from .82 in the earlier period (1980-1990) to .78 in the recent period (1991-2013). The changes in individual major economies' oil dependences are discussed as follows.

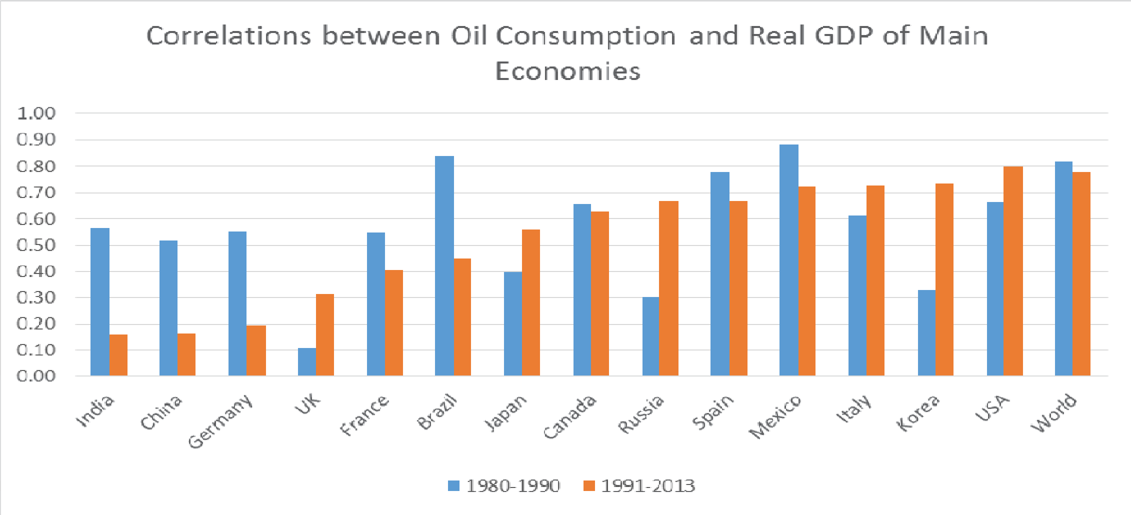

Figure 6. Oil Dependences of the Major Economies: Correlation Coefficients between Oil Consumption and Real GDP of Major Economies in 1980-1990 vs. 1991-2013, Sources: BP 2014, USDA 2014

The major economies that had relatively high oil dependences in the first period and reduced oil dependences in the second period included Mexico (from .89 to .72), Brazil (from .84 to .45), Spain (from .78 to .67), and Canada (from .66 to .63). On the other hand, the economies that had relatively low oil dependences in the first period and even lower oil dependences in the second period included India (from .57 to .16), China (from .52 to .16), Germany (from .55 to .19), and France (from .55 to .41).

In contrast, the United States had a relatively high oil dependence in the first period and even higher oil dependence in the second period (from .66 to .80), thus having become the most oil dependence economy among the 14 major economies. Major economies that had initially low oil dependences, but significantly higher oil dependences in the second period were Korea (from .33 to .73) and Russia (from .30 to .67). Economies with increased oil dependences in the second period also included Italy (.61 to .73), Japan (from .40 to .56), and the United Kingdom (from .11 to .31).

While China's low oil dependence in the recent period can be explained by its lower level of economic development and purchasing power, Germany's significantly reduced oil dependence in this period cannot be explained with the same reasons of low development level. As matter of fact, Germany's oil dependence that was much lower than those of all other developed economies, especially the United States and South Korea was untypical for a highly productive, manufacturing developed economy and represented an exception to the oil dependence of the developed countries. The finding of Germany's much lower oil dependence helps explain in part why the German economy proved "particularly resistant against recent crisis pressures," such as the oil price hikes prior to the world financial and economic crisis in 2008-2009 and the acute current Euro Zone fiscal crisis (Funk 2012).

The findings of the U.S. and German economies' extremely different oil dependences have several implications. First, the findings allow us to confidently associate the rise in the oil consumption with the growth in the world economy and the

U.S. economy and vice versa during the recent ten years. At the same time, these revelations expose the U.S. economy's and the world economy's soft underbelly, their heavy reliance on oil making them extremely vulnerable to the short-term oil shocks such as oil supply shortages, oil price hikes, and long-term oil crises such as oil peak and oil depletion.

In addition, this revelation also suggested that if the U.S. economy and the world economy do not make effort to change their heavy oil reliance in the future, the future short-term oil shocks will have severe long-term implications for these oil dependent economies. It indicated that it is not only in the interest of the U.S. economy, but it is also its moral responsibility as the world's top economy to reduce its overreliance on oil in order to reduce these vulnerabilities in the face of short-term and long-term oil crises.

2.4.2. Coal Dependence

Next, this study moved on to examine the coal dependence of the major economies. Like the oil dependence analysis in the previous section, the coal dependence analysis in this section was based on two methods, first the method of analyzing the shares of coal consumptions in the total energy mixes, and then the method of analyzing the correlations between the coal consumptions and real GDPs.

In the coal share analysis, the study first looked at the share of the coal consumption in the total primary energy consumption for individual major economies and the world economy on an annual basis, and then compared these annual coal shares over the entire 44-year examination period. The findings of this analysis are discussed as follows.

First, the four major economies with highest coal shares (67 percent, 55 percent, and 30 percent respectively) in 2013 were China, India, South Korea and Japan. The coal dominances of these major economies were associated with two features: a) all these coal intensive economies were located in Asia, and b) the top two of the three most coal intensive economies, China and India, were also the two least oil intensive economies as discussed in the previous section.

Second, among other major economies whose coal shares were also below the world economy's average coal share (30 percent), six had coal shares between 27 percent and 11 percent (i.e. Japan 27 percent, Germany 25 percent, United States 20 percent, and the United Kingdom 18 percent, Russia 13 percent and Italy 11 percent) and five had coal shares low than 10 percent (i.e. Spain 8 percent, Mexico 7 percent, Canada 6 percent, and both France and Brazil 5 percent).

Third, examining the long-term change in the major economies' coal shares, the EU economies' coal shares experienced more drastic reductions then other major economies from 1980 to 2013. For example, France's coal shares reduced 66 percent, Spain's 56 percent, and the United Kingdom's 48 percent, and Germany 36 percent. While the most coal intensive economies, China and India, insignificantly reduced their coal shares (7.9 percent and 1 percent), Japan and Mexico significantly increased their coal shares, i.e. 67 percent and 1.2 times respectively. Comparing the changes in coal shares between the 1980-1990 period and the 1991-2013 period, most reductions of coal shares, especially in EU economies, took place in the second period. However, major increases in coal shares of several economies also took place in the second period, for example, 1.2 times in Mexico, 54 percent in Japan, 24 percent in South Korea.

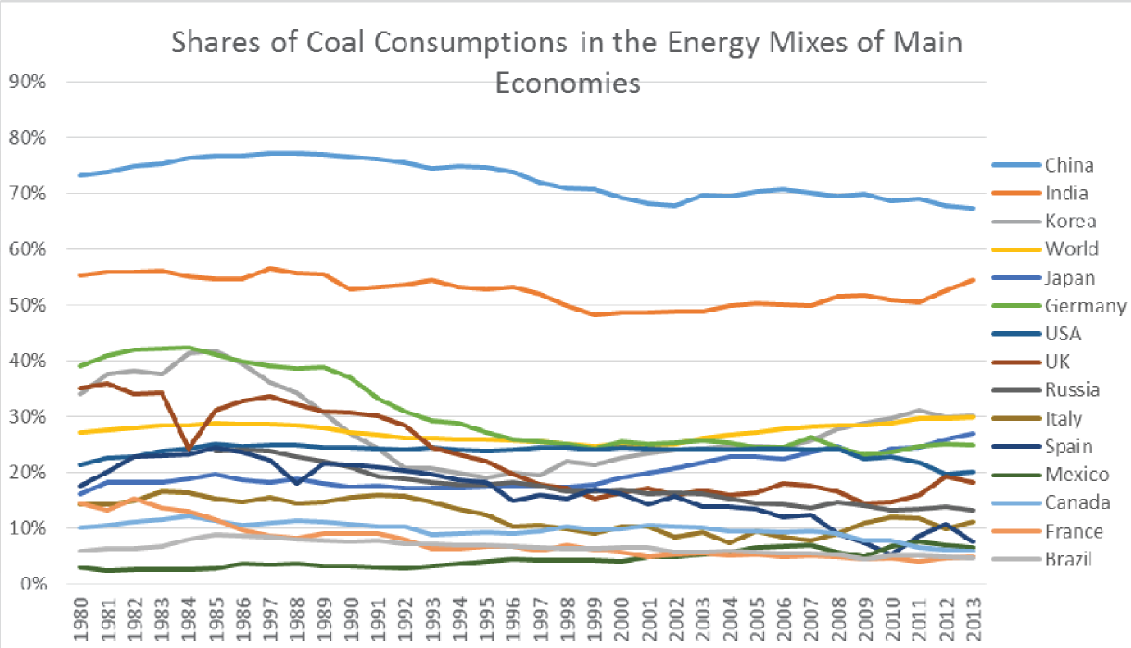

Figure 7. Coal Dependence: Share of Coal in Total Energy Mix of Major Economies, Source: BP, 2014

In the coal-GDP correlation analysis, this study used the coal consumption data and the real GDP data of the major economies during the period between 1980 and 2013. This study first looked at the annual changes in the world GDP and the GDPs of the 14 major economies and the annual changes in these economies' coal consumptions during the period and then ran the correlation analysis between these two time series. The correlation analysis between the GDP and coal consumption of the five investigated economies resulted in respective correlation coefficients of these economies to indicate their individual coal dependences.

The results of this correlation examination showed more a much more complicated picture than the coal share examination. First, economies with high coal shares tended to have high coal-GDP correlation coefficients. China was an outstanding example; with an annual average coal share of 75 percent in the period between 1969 and 1979, its coal-GDP correlation coefficient was .81, the highest among the major economies in the period. Similarly, when Germany and South Korea had relative high annual average coal shares of 43 percent and 36 percent in the same period, their coal-GDP correlation coefficients reached 58 percent and 50 percent respectively.

However, other factors such as the differences between the changes in the coal share and the GDP also significantly determined the coal-GDP correlation coefficients. For example, although China reduced its annual coal share by only 7.9 percent in the period between 1980 and 2013, its coal-GDP correlation coefficient reduced significantly to .44 in this period compared with .81 in the previous period because it maintained a high annual GDP increase of around 10 percent in the same period. Similarly, when France, Spain, the UK and Germany dramatically reduced their coal shares by approximately 66 percent, 56 percent, 48 percent and 36 percent, their coal-GDP correlation coefficients reduced to .21, .16, .17 and .15 respectively in the period between 1980 and 2013. Conversely, because of the dramatic increase of 67.4 percent in Japan's annual coal share in this period, its coal-GDP correlation coefficient reached 58 percent despite its much lower coal shares of 20 percent.

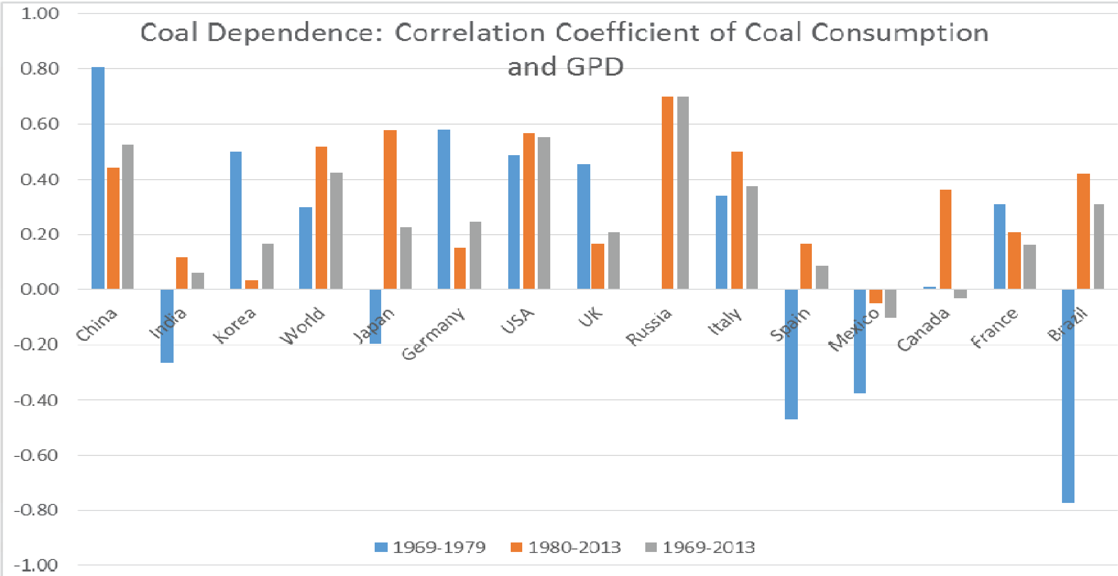

Figure 8. Coal Dependences of the Major Economies: Correlation Coefficient between Coal Consumption and Real GDP of Major Economies in 1969-1979 vs. 1980-2013 vs. 1969-2013
Sources: BP 2014, USDA 2014

However, India and Russia were the two economies whose coal-GDP correlation coefficients posed more challenges to their interpretations. India had the second highest average annual coal shares (57 percent in the first period and 55 percent in the second period), but its coal-GDP correlation coefficients in these two periods were only -.27 percent and 12 percent respectively. Since the changes in its average annual coal shares, its negative and low coal-GDP correlation coefficients in these two periods were mainly associated with low and irregular economic growth. In contrast, although Russia had relatively low coal share (23 percent) in the period between 1980 and 2013, its coal-GDP correlation coefficient in this period reached .70, the highest in the second period. Since the average low coal share reflected a decrease by 31 percent, its high coal-GDP correlation coefficient was mainly associated with its drastically reduced economic size in the 1990s and the virtually stagnant economic growth during the entire investigative period.

One important issue arose after the Germany's decision to phase out its nuclear power plants in the wake of the Fukushima nuclear disaster (Sovacool 2008, Burgherr and Hirschberg 2008, Hippel 2011, Normile 2012, Revkin 2012, Hippel 2011) if and to what extent the governments' decisions impacted Germany's coal consumption, and more generally, if the nuclear disasters had negative impacts on coal consumptions in the major economies. To acquire insights into these two issues, this study investigated the annual changes in coal consumptions of the major economies before and after the Chernobyl nuclear disaster and since the Fukushima nuclear disaster. The results of this investigation, which are presented in Figure 9, did identity a negative impact of the German government's decision after Fukushima. Germany's annual average changes in coal consumption rose from 0.4 percent before the Chernobyl nuclear disaster and -2.4 percent between the Chernobyl disaster and the Fukushima disaster to 3.4 percent since the Fukushima nuclear disaster, which Pearce (2014) considered Germany's "detour" on its road to green energy.

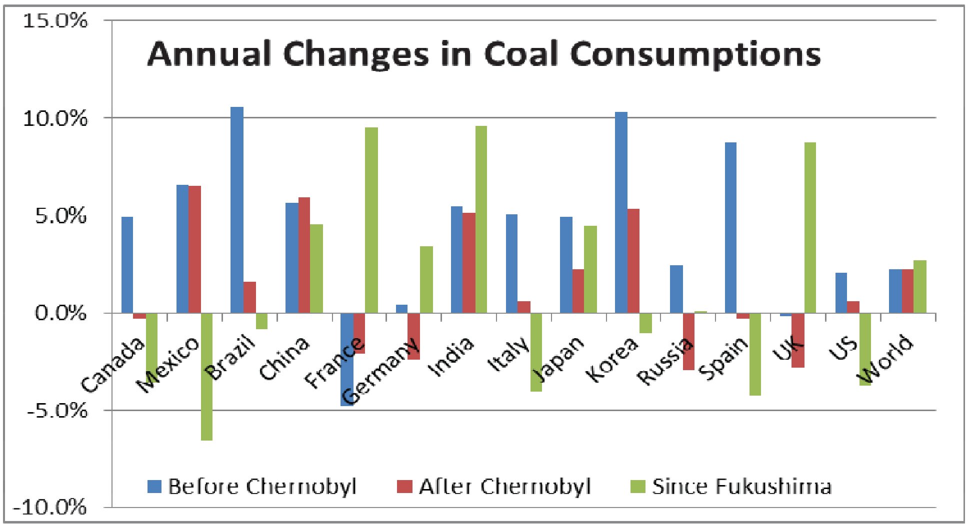

Figure 9. Change in Coal Dependence before Chernobyl, between Chernobyl and Fukushima, and since Fukushima, Source: BP, 2014

However, the Fukushima nuclear disaster seemed to have a more notable impact than the Chernobyl nuclear disaster on the coal consumptions in India, France, Japan and Germany as the reduced growth rates or increased decrease rates in the nuclear power consumptions (1.7 percent vs. 9.8 percent, -2.1 percent vs. 2.3 percent, -53.9 percent vs. 1 percent, and -5 percent -0.5 percent respectively) since the Fukushima nuclear disaster helped drive coal consumptions by 9.6 percent, 9.5 percent, 4.5 percent, and 3.4 percent a year respectively versus 5.2 percent, -2.1 percent, 2.3 percent and -2.4 percent respectively in the previous period between the two nuclear disasters.

The coal dependence analysis in this and the previous section revealed that there was a divide between the developed countries and developing countries in coal dependence. While developing countries were largely stuck with coal, a less expensive energy source, the developed countries were able to move away from this most polluting and most carbon intensive energy source. These converging trends in the two groups' compositions of black energy consumption determined the higher yet declining CO_2 emissions in developed economies and lower yet rising CO_2 emissions in developing economies.

The coal dependences of the two fast growing industrializing countries indicated important policy implications by explaining the daunting environmental and health challenges and costs these two countries' economic developments face as they have become the world's energy intensive manufacturers. At the same time, all major developed countries, including Germany that had relatively lower oil dependences had lower coal dependences than the developing countries China and India in the entire investigated period. However, while the United States' and Japan's coal dependences were initially low, was not changed significantly over the course of 44 years, and German's coal dependence was initially high, but has experienced a significant decrease to a low level (around 25 percent) similar to Japan's in 2013.

Considering Germany's relative low oil dependence as discussed earlier, its significant departure from its initial coal dependence was a very important transformation that needs more dedicated research, whose results could have some implications for China's and India's transformation from their major coal dependences. Combined with its relatively low oil dependence, Germany's departure from its coal dependence constituted the decarbonization of its economic development, which can be seen as a role model for other developed economies (OECD 2012).

2.4.3. Natural Gas Consumption

In addition to major economies' dependences on oil and coal, the study also examined their natural gas consumptions. The focus of the investigation was the shares of their natural gas consumptions in their respective total fossil and non-renewable fuel consumptions. The results of the study informed us of several interesting characteristics and trends, which have significant implications for the global energy transformation.

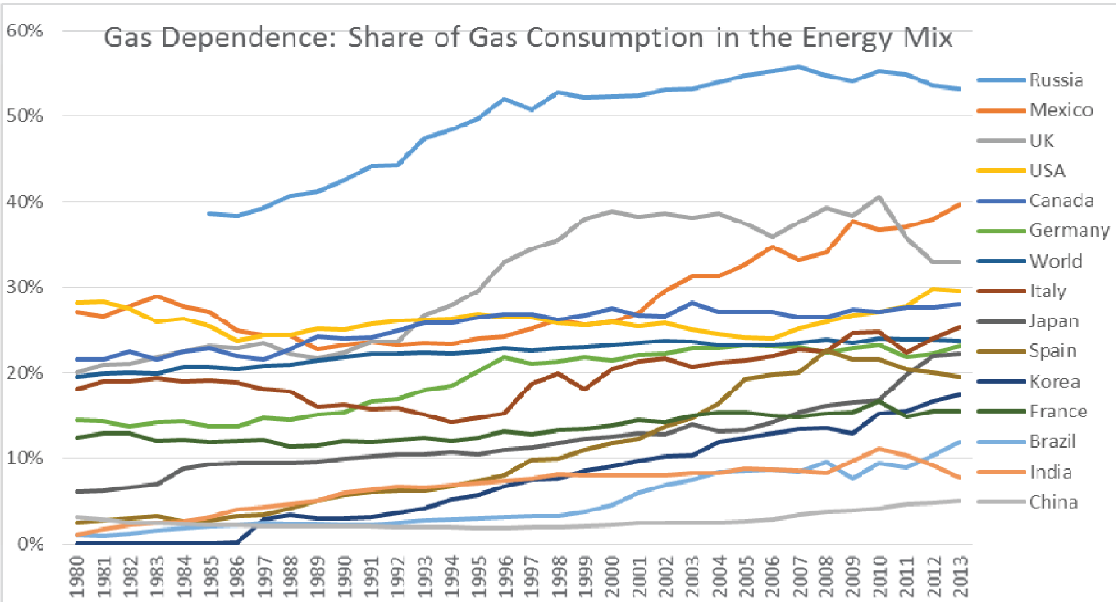

Figure 10. Gas Dependence: Shares of Natural Gas in Total Energy Consumptions of Major Economies (1980-2013), Sources: BP 2014.

First, all major economies have increased their natural gas shares during the investigative period. The increases in their natural gas shares ranged from only 5 percent for the United States to approximately 2.6 times, 5 times, 6.5 times, 7 times, and 11.3 times for Japan, South Korea, India, Spain, and Brazil respectively.

Second, the natural gas shares of Russia (54 percent), Mexico (40 percent), the United Kingdom (33 percent), the United States (30 percent), Canada (28 percent) and Italy (25 percent) in 2013 were above the world average (24 percent).

Third, the three major developing economies—China, India, and Brazil, had lowest natural gas shares, i.e. 5 percent, 8 percent, and 12 percent respectively in 2013. Since natural gas has lowest CO_2 emissions among the carbon fossil fuels, the low natural gas shares of these fast growing major developing economies indicated a disadvantage of their black energy structure, which put a rising climate change pressure on their rapid economic rises.

Since the carbon emissions of natural gas is around 27 percent lower than oil, and between 43 and 49 percent lower than coal depending on its quality (EIA, 2012), most developed economies' higher natural gas shares in fossil fuels constituted an additional favorable, competitive edge of over the three fast growth developing economies in carbon intensity reduction.

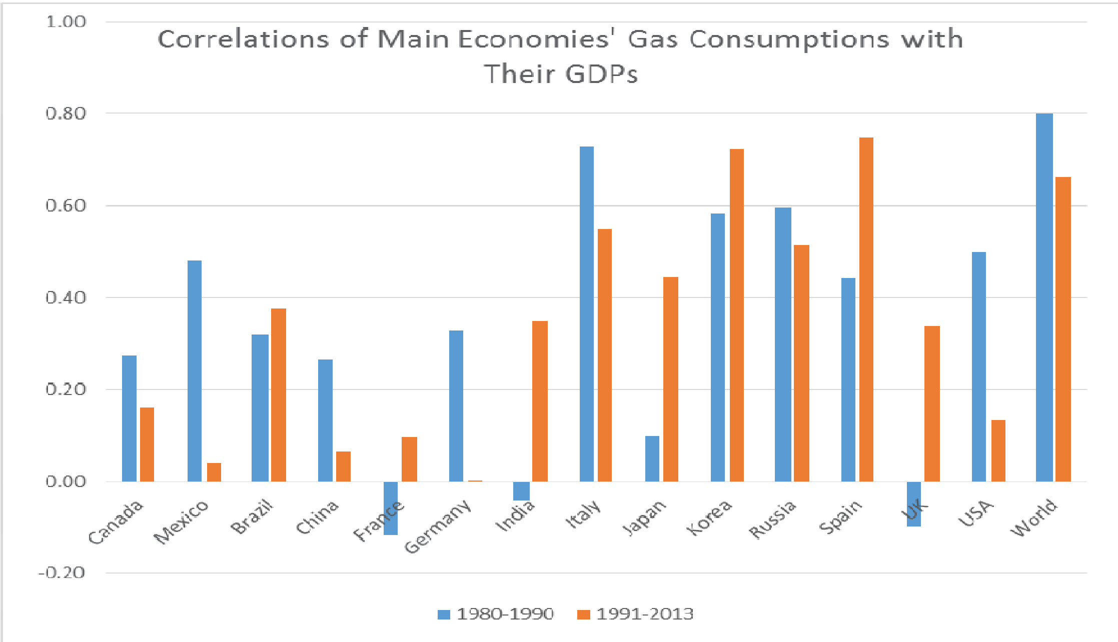

Figure 11. Gas Dependence: Correlation Coefficients between Natural Gas Consumption and Real GDP of Major Economies in 1980-1990 vs. 1991-2013, Sources: BP 2014, USDA 2014

The comparative correlation analysis of the natural gas consumptions and real GDPs of the major economies showed several interesting findings. First, major economies with high natural gas consumption shares had relatively higher correlation coefficients between natural gas consumptions and real GDPs. For example, Russia which had top natural gas shares of 40 percent for the period 1980-1990 and 52 percent for the period 1991-2013 respectively had correlation coefficients of .60 and .51. Similarly, other major economies with relatively high natural gas shares also had high natural gas-GDP coefficients. For example, high natural gas-GDP coefficients for Italy, Spain, and South Korea were.73 and .55, .44 and .75, and .58 and .72 for the two investigative periods.

In contrast, major economies with low natural gas shares had also relatively low correlation coefficients between natural gas consumptions and real GDPs. For example, the natural gas-GDP correlation coefficients for China, which had natural gas shares of 2 percent and 3 percent in the two period, were only .27 and .07.

Next, increased natural gas shares were often paralleled by higher correlation coefficients between natural gas consumptions and real GDPs. For example, when the natural gas shares in the United Kingdom, Japan, Spain, South Korea, Brazil, and India were increased from 22 percent, 8 percent, 3 percent, 2 percent, 2 percent and 3 percent in 1980-1990 to 35 percent, 14 percent, 14 percent, 10 percent, 6 percent, and 8 percent in 1991-2013 respectively, their correlation coefficients between natural gas consumptions and real GDPs also rose from .10 to .44, .44 to .75, .58 to .72, .32 to .37, and -.04 to .35 respectively.

In addition, recent growth in shale gas production played a significant role in the growth in the U.S. natural gas production. According to EIA data (2013), the shale gas's contribution to total U.S. gas production rose from less than 2 percent in 2005 to more than 20 percent in 2010, and set another record for U.S. natural gas production in 2013 and thus raised the share of natural gas consumption in the total fossil fuel consumption from 27 percent in 2007 to 32 percent in 2013 as the result of shale gas growth, with total daily dry output for the first ten months of 2012 averaging 1.77 Gm3/day (62.7 Bcf/day). It was projected that the U.S. natural gas production would increase around 40 percent from 2013 to 2040 (EIA, 2013).

The natural gas's relative lower CO_2 emissions than coal's and the potential displacement of coal by shale gas in power generation were also used as black "green" arguments for shale gas producing companies to support their business expansion and advertised by shale gas investors as a "bridge" of the current carbon-based economy to a renewable energy-based economy.

However, a comprehensive modeling by fourteen teams from different organizations (Romm, 2013) suggested that abundant and cheap natural gas would displace carbon-free energy rather than coal, and therefore have little net impact on reduction of the U.S. CO_2 emissions, especially after 2020.

Wang et al. (2014) also confirmed that shale gas production increased 12 fold from 2000 to 2010, contributing to not only significantly cheaper price of US domestic natural gas price of about $2 per million British Thermal Unit (BTU) in the first half of 2012, but also sharply reduced US carbon emissions from fossil-fuel combustion by 430 million ton between 2006 and 2011 and increased new jobs by 600,000 in the US by 2010.

At the same time, Wang et al. also pointed out the hydraulic fracturing's adverse impacts on long-term environmental sustainability because of the associated intensive water use, pollution in the ground water, significant methane emissions during the shale gas exploration and production, and possibility of inducing earthquakes, and called on enforcement of stronger regulations to minimize environment and health risks.

However, other studies, while recognizing the economic contribution of shale gas revolution, found that significant methane leaks during the shale gas exploration and production could be attributed to high US methane emissions (Arthur et al. 2008; Adams et al. 2011; Belvalkar and Oyewole 2010; Peduzzi and Harding 2012; Pearce, Fred. 2013; Tollefson 2013; Busch and Gimon 2014). Since methane is a much more potent greenhouse gas, these studies dispute the perceived positive role of shale gas replacing coal in reducing CO_2 emissions and warned instead that could accelerate global warming.

In addition, an International Energy Agency (IEA, 2012) report found that the growth of shale gas production would, on the one hand, have both positive and negative impact on deployment of renewables, and, on the other, have to overcome substantial social and environmental concerns associated with its extraction, an intensive industrial process which imposes a larger environmental footprint than conventional natural gas development.

3. Carbon Dependence

3.1. Fossil Fuel Consumption and CO_2 Emissions

Next, this study moved on to examine the major economies' fossil fuel consumptions and related CO_2 emissions. For this analysis, both the total fossil consumption data and the total CO_2 emission data of the United States, Germany and China in the period between 1965 and 2013 were examined.

This examination has generated several interesting observations. First, while the fossil consumption and CO_2 emissions in the examined period correlated perfectly in the United States (.99653) and China (.99998), they displayed a negative correlation in Germany (-0.73982), indicating that while the energy structures in the United States and China remained largely unchanged carbon, the energy structure in Germany has experienced a tangible transformation away from the fossil fuels.

This remarkable difference in the energy structures between Germany on the one hand and the United States and China on the other was also confirmed by the dramatic change in Germany's coal dependence (see Figure 7 and Figure 8).

Second, while the fossil fuel consumption in Germany largely remained the same with a slight reduction and its related CO_2 emissions were reduced 12.7 percent in this period, the fossil fuel consumptions and CO_2 emissions in both the United States and China experienced drastic increases. This was especially true for China since its accession to the World Trade Organization (WTO) in 2002 (see Figure 12).

With China's dramatically increased fossil fuel consumption, the even more dramatic surge in its CO_2 emissions was much more startling in the face of the need of, and the global effort in, reducing CO_2 emissions. The relentless upward trend of China's CO_2 emissions in the recent years indicated the dilemma the developing country China is facing in terms of its economic development; it has to face unprecedented challenges that the developed countries did not have to face in their industrial revolution and economic development (Andersson and Karpestam 2013, Li et al. 2013, Tian et al. 2013, Zhou et al. 2013, Zhao et al. 2013, Zhou et al. 2013, Li et al. 2014, Rene et al. 2014, Shao et al. 2014, Yuan et al. 2014, Zhang and Lahr 2014).

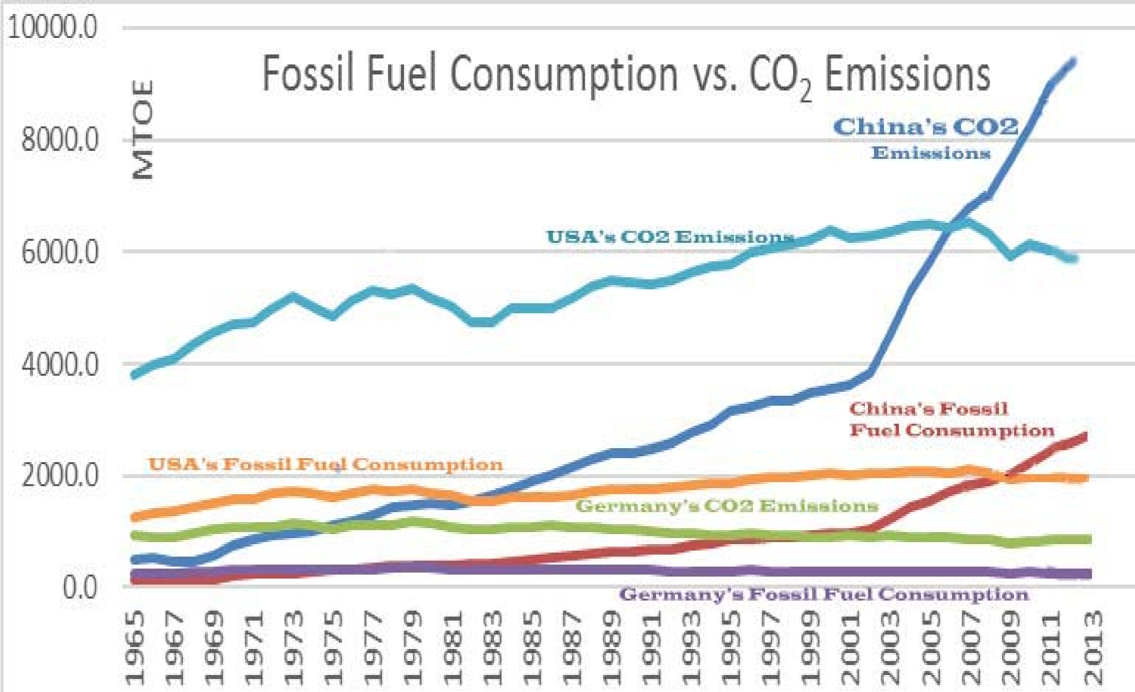

Figure 12. Fossil Fuel Consumption and CO_2 Emissions of Selected Economies (1965-2013), Sources: BP 2014

The developing countries now urgently need to implement effective policy tools to reverse this rising trend and to adopt different strategies than the developed countries to manage their carbon reduction plans. At the same time, as these fast industrializing countries produce goods not only for their domestic consumption, but also for the consumption of the developed countries, the developed countries have the responsibility to do their shares to help these countries green their manufacturing and mitigate the resulting environmental and ecological impacts.

While the number of total fossil fuel consumption and the related CO_2 emissions indicated the needs for addressing the ecological impact of the economic development in general terms, comparing various countries' black energy consumption per capita provided us the information on equity issues and the information how to address the ecological impact of the economic development in the differentiated manner.

3.2. Carbon Intensity

Next, this study took a look at the carbon intensity of the major economies, or the CO_2 emitted by generating a unit of GDP. A two-step approach were involved in this investigation. Both steps used the data of annual CO_2 emissions of the 14 major economies from 1969 to 2013. The difference between the two steps was that the first approach used in addition the data of real (adjusted to the 2005 U.S. dollar) GDP of the

14 major economies from 1969 to 2013, and the second step used in addition the data of annual PPP-adjusted GDPs of the 14 major economies from 1980 to 2013.

This two-step approach was designed as a combined solution to the gap between the needed comparability and the partial data availability. Ideally, using PPP-adjusted GDP data would be more accurately compare the carbon intensities of the developed economies with those of the developing economies. However, PPP-adjusted GDP data were only available for the period since 1980 from the *IMF World Economic Outlook*. Limiting the investigation to using the PPP-adjusted GDP data would make the investigation of the earlier period between 1969 and 1980 impossible, in which the carbon intensities of some developing or transition economies, especially China, were much higher. This approach would allow more accurate comparison of the major economies' carbon intensities for the more recent period, but greatly impair the historical comparison for a longer period, thus the value of the investigation. Using this two-step approach instead allowed the study to not only to examine the accuracy of the carbon intensity comparison for the more recent period between 1980 and 2013, but also look into the historical background of the carbon intensity dynamics in a longer period than the period with the available PPP-adjusted GDP data. The graphic illustrations of the results of this two-step investigation are presented side by side in Figure 13 and Figure 14.

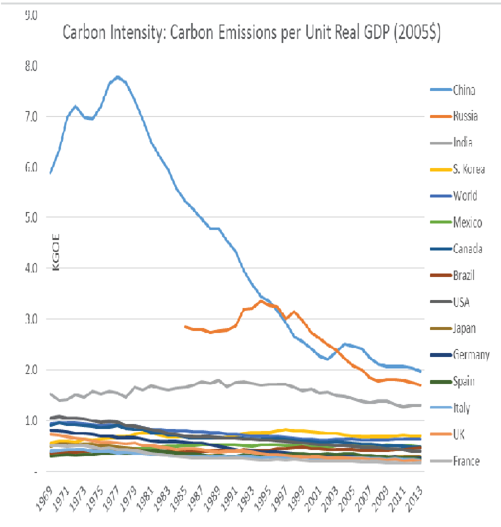

Figure 13. Carbon Intensity of Major Economies (Real GDP, Adjusted to 2005$) (1969-2013)
Sources: BP 2014, USDA 2014.

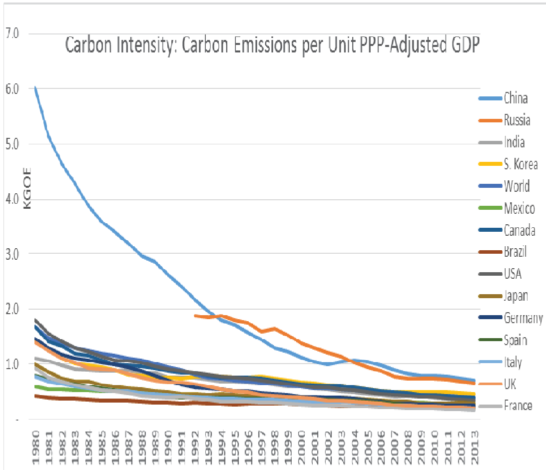

Figure 14. Carbon Intensity of Major Economies (PPP-Adjusted GDP) (1980-2013)
Sources: BP 2014, IMF 2014.

The results of the carbon intensity investigation revealed several interesting insights. First, China's high carbon intensity stood out from all other major economies' using both the real GDP method and the PPP-adjusted GDP method. In the starting year of 1969 using real GDP method, China's carbon intensity was extremely high, much higher than those of all other major economies, ranging from almost four times to more than 11 times other economies' examined. It reached the top level in 1978—the year China started its economic reforms—almost five to more than 16 times other economies' carbon intensities examined. Since then, it went continuously downward with a small rebound between 2003 and 2006.

Second, other transitional (former Socialist) and developing economies shared similar feature of high carbon intensity, with Soviet Union/Russia's carbon intensity tripling the developed economies' and India's doubling them. Third, the developed countries collectively had relatively low carbon intensities.

The carbon intensity analysis of the major economies indicated that China's high carbon intensity has historical reasons as a both Socialist and developing country, and its high carbon intensity has been decreasing as it moved away from the developing pattern of a Socialist command economy and its market economy grew more and more mature. On the other hand, as of 2013, China's carbon intensity was still much higher than other major economies, ranging from 20 percent higher than Russia's and 10.4 times higher than France's using real GDP method or 10 percent higher than Russia's and 3.2 times higher than France's using PPP-adjusted GDP method. On average, China's carbon intensity was 4.5 times higher than other major economies using real GDP method or 1.5 times higher than other major economies using PPP-adjusted GDP method. This indicated that China still has to make substantial efforts to reduce its carbon intensity.

This carbon intensity analysis has significant policy implications. It suggested that China, Russia, and India need to focus their carbon reduction efforts on reducing their carbon intensities. In this sense, China's d and China's determination to reduce its carbon intensity by 40-45 percent from 2005 to 2020 was a necessary and important energy policy that considered a combination of several factors, including China's current relatively low per capita black energy consumption and income, its high carbon intensity and high total high carbon emissions, and its current position in the world economy as a manufacturing center with heavy industry (Shapiro 2012, World Bank 2014).

At the same time, it also indicated that even if China accomplished its 40-45 percent carbon intensity reduction goal by 2020, its carbon intensity would still be much higher than the developed countries'. This indicated that in addition to accomplishing its 40-45 percent carbon intensity reduction goal by 2020, China needs continue reducing its carbon intensity after 2020 (Dou 2013, Gambhir et al. 2013, Lu et al. 2013, Wang and Liang 2013, Wang et al. 2013, Wu et al. 2013, Lin and Long 2014, Qi et al. 2014, Wang et al. 2014, Yu et al. 2014, Yuan et al. 2014).

3.3. CO_2 emissions Per Capita

Next, this study examined the major economies' CO_2 emissions per capita. For this analysis, the CO_2 emission data of the United States, South Korea, Japan, Germany, China, Brazil, and India in the period from 1969 to 2013 and their population data in the same period are used.

The results of the comparative analysis revealed both common characteristics and trends and exceptions to these common trends. Generally speaking, the annual CO_2 emissions per capita in the developed countries were decreasing, but they were still significantly higher than those of the developing economies. This was true for the United States, Germany, the United Kingdom, and France, in which the CO_2 emissions per capita decreased from 21.9, 13.1, 12.9, and 8.6 tons oil equivalent (TOEs) in 1969 to 18.7, 10.4, 8.2, and 6 TOEs in 2013, by 14.5 percent, 20 percent, 37 percent, and 30 percent respectively.

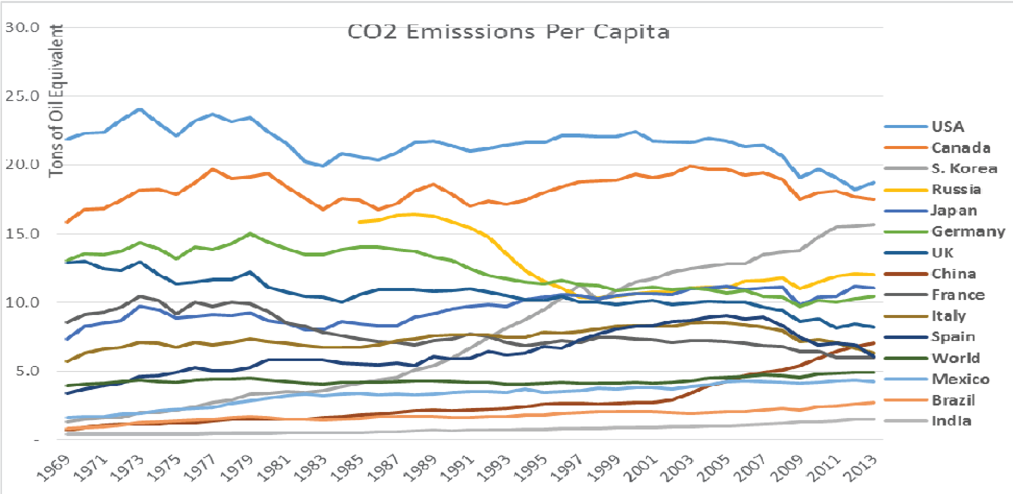

Figure 15. CO_2 Emissions Per Capita of Major Economies (1969-2013)
Sources: BP 2014, UNDESA 2014

However, exceptions to this common trend for developed countries were Canada, Japan, South Korea, Italy, and Spain. While the CO_2 emissions per capita rose in Canada, Japan, Italy, and Spain from 15.8, 7.4, 5.7, and 3.4 TOEs in 1969 to 17.5, 11, 6.3, and 6.1 TOEs in 2013 by 10.3 percent, 50 percent, 10 percent and 81 percent respectively, South Korea's CO_2 emissions per capita soared by 10.6 times from 1.3 TOEs in 1969 to 15.7 TOEs in 2013, a level only lower than those of the United States and Canada and much higher than those of all other major economies under investigation.

The common trend for the developing countries was initially low but then rising CO_2 emissions per capita. This was true to different extents for China, India, and Brazil. While the CO_2 emissions per capita in India and Brazil rose from .4 and .8 TOEs in 1969 to 1.5 and 2.7 TOEs respectively in 2013, they soared in China by 8.5 times from .7 TOE in 1969 to 7 TOEs in 2013, a level still lower than those of most developed economies, such as the United States, Canada, South Korea, Japan, and German, and the United Kingdom, but higher not only than those of other developing economies such as Mexico, Brazil, and India, but already those of the developed economies Spain, Italy and France. Exception to this developing and transition economy group trend was Russia, which had initially high but then decreasing CO_2 emissions per capita, from 15.8 TOEs in 1985 to 12 TOEs in 2013, a decrease by 24 percent.

A trend of carbon shift from some developed economies to developing economies was observable during the investigative period. For example, the carbon emissions reduced from the highest annual per capita CO_2 emissions of 24.1 TOEs in 1973 to the lowest annual per capita CO_2 emissions of 18.2 TOEs in 2012 in the United States, from 15 TOEs in 1979 to 9.7 TOEs in 2009 in Germany, from 13 TOEs in 1973 to 8.1 TOEs in 2011 in the United Kingdom, and from 10.5 TOEs in 1973 to 6 TOEs since 2011 in France were all "balanced" by the carbon increase from the lowest annual per capita CO_2 emissions of 1.3 TOEs in 1969 to the highest annual per capita CO_2 emissions of 15.7 TOEs in 2013 in South Korea, from 0.7 TOEs in 1969 to 7 TOE in 2013 in China. Obviously, the wealthier economies have reduced their carbon emissions in considerable part because manufacturing and heavy industries have left these countries.

These insights confirmed the findings of previous studies, which attributed the international inequality in per capita CO_2 emissions and the between-group inequality mainly to the inequalities in per capita income levels (Duro and Padilla 2006). The group trends indicated that the developed countries, especially the United States, Canada, and South Korea, have the moral and economic responsibilities to dramatically and drastically reduce their CO_2 emissions per capita. While the decreasing trend of CO_2 emissions per capita in main developed economies was encouraging, the rising trend of CO_2 emissions per capita in some other main developed economies with high CO_2 emission levels was alarming. Also concerning was the CO_2 emission rising level in rapidly growing and most populous developing economies, especially China, whose per capita CO_2 emission level has already reached the low end of the developed economies.

3.4. Changes in GDPs, CO_2 Emissions, and Carbon Intensities

In addition, this study investigated the changes in GDPs, CO_2 emissions, and carbon reductions of the selected countries and compared these data with each other. For this investigation, three sets of data—annual changes in GDP, CO_2 emissions, and carbon intensities of Russia, Italy, the United Kingdom, Germany, France, Spain, Japan, the United States, Canada, Mexico, Brazil, India, South Korea, and China, as well as those of the world average, were used from the examination period from 1970 to 2013. The results are presented in the following Figure 16.

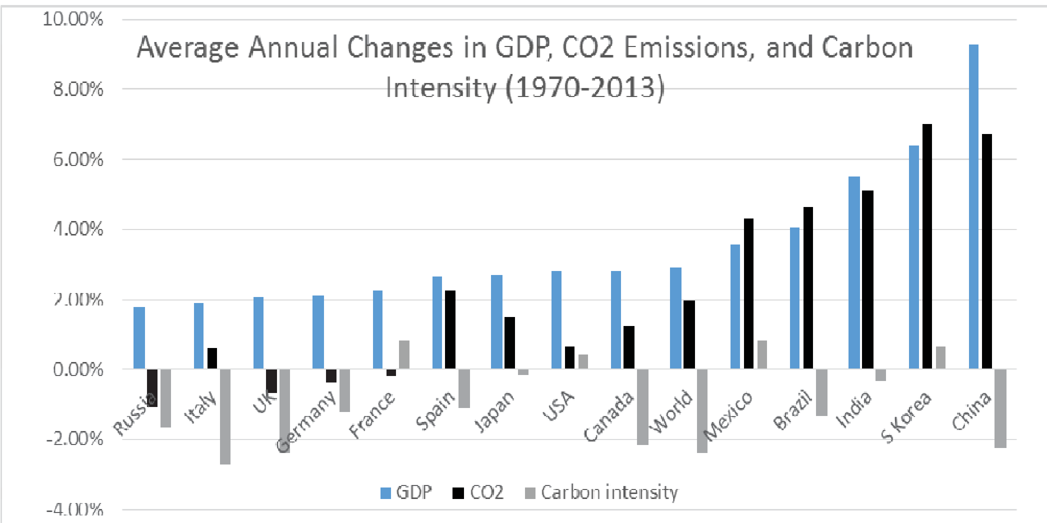

Figure 16. Annual Average Growth Rates in GDP and CO_2, Reduction in Carbon Intensity of Major Economies (1970-2013), Sources: BP 2014, IMF 2012, USDA 2014, World Bank 2012

The results revealed interesting common trends in annual average GDP growth rates and annual average changes in CO_2 emissions that differentiated the developed economies from the developing economies.

On the one hand, most developed economies' annual average GDP growth rates ranging from Italy's low of 1.89 percent to Canada's high of 2.81 percent were lower than the world average GDP growth rate of 2.93 percent, and most developed economies' annual average increase rates in CO_2 emissions were also lower than the world average increase rate of 1.97 percent.

Spain and South Korea represented exceptions to this developed economies' group trend of slower GDP growth rates and slower CO_2 emissions increase rates. While Spain deviated from the developed economies' common feature of low CO_2 emissions increase rates only by presenting an annual average CO_2 emissions increase rate (2.28 percent) higher than the world average rate of 1.97 percent, South Korea decisively rebelled against the developed economies' trends by positioning itself as the only developed economy with both an annual average GDP growth rate and an increase rate in CO_2 emissions not only higher than the world annual averages, but also higher than most main developing economies'. In fact, with its rate of 6.37 percent, South Korea's annual GDP growth was higher than those of all major economies except for that of China, and with its annual average increase rate of 7 percent, South Korea's CO_2 emissions grew the fastest among all major economies', even higher than its annual GDP growth rate.

On the other hand, developing economies' annual average GDP growth rates ranging from Mexico's low of 3.56 percent to China's high of 9.3 percent were in general higher than the world average GDP growth rate of 2.93 percent and their annual average increase rates in CO_2 emissions ranging from Mexico' low of 4.31 percent to China's 6.69 percent were also much higher than the world average increase rate of 1.97 percent.

With its highest annual average GDP growth rate of 9.3 percent in the 44-year period, China's CO_2 emissions also grew at a high rate of 6.69 percent, second highest increase rate among the major economies', only next to that of South Korea. At the same time, China's annual carbon intensity also dropped by 2.24 percent a year, the third highest carbon intensity reduction after 2.7 percent in Italy and 2.42 percent in the United Kingdom.

The data also showed that other major economies under investigation also experienced decreases in annual carbon intensities, except for France, Mexico, and South Korea, whose annual average carbon intensity increased instead by 0.86 percent, 0.86 percent and 0.64 percent respectively.

The only exception to this developing economies' trend of higher economic growth rate and higher increase in carbon emissions was Russia, whose annual average GDP growth of 1.78 percent and its annual average change in CO_2 emissions of -1.07 percent were both below the world averages. Russia's low economic growth and carbon reduction, which made it looking more like most developed economies rather than developing economies, were however caused by the economic collapse of its predecessor, the former Soviet Union after its political disintegration.

The comparison of the two groups' diverging trends of GDP and CO_2 emissions showed that the increase in CO_2 emissions significantly was correlated with the economic growth; i.e. high economic growth was correlated with higher CO_2 emissions, and vice versa.

4. Nuclear Dependence

The term of nuclear dependence used in this study was defined as the share of an economy's nuclear energy consumption in its total black energy consumption. Although nuclear power is considered carbon-free and does not, like carbon-based fossil fuels, emit huge amounts of CO_2 and other pollutants that cause climate change and environmental degradation, its generation process is far from being clean. It requires uranium that must be mined and transported to nuclear power plants. In addition, nuclear power generation produces radioactive nuclear waste, which is non-biodegradable and remains highly radioactive and therefore dangerous for lives and environment for thousands of years. Therefore, the investigation of nuclear dependence is of utmost importance.

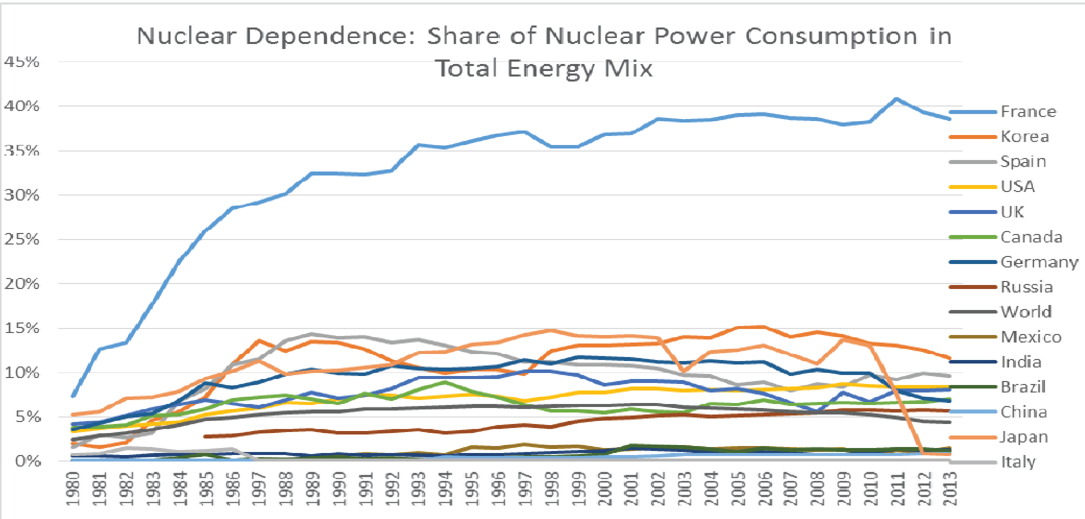

Figure 17. Nuclear Dependence: Shares of Nuclear Power Consumption in Total Energy Consumptions in Major Economies (1980-2013)

The results of the investigation of major economies' nuclear shares in their respective total energy mixes indicated that the nuclear dependence was a phenomenon associated with developed economies. While the major developing economies China and India only had very low nuclear shares of 0.9 percent and 1.3 percent respectively in 2013, the developed economies had much higher nuclear shares in the investigated period between 1969 and 2013.

France was the world's top nuclear dependent economy, whose average annual nuclear share was already 22 percent in the 1980's, 35 percent in the 1990's, and 38 percent since 2000. However, its nuclear share started to decline slightly after it had reached 41 percent in 2011. Japan's nuclear share reached its peak of 15 percent in 1998, and then started to decline to 8 percent before the Fukushima nuclear disaster.

Spain had its highest nuclear share of 14 percent in 1993, which declined to 9 percent in 2011 and recovered to 9.6 percent in 2013. South Korea experienced its top nuclear share of 15 percent in 2005 and 2006, which dropped to 11.6 percent in 2013. Other developed economies also reduced their nuclear dependences.

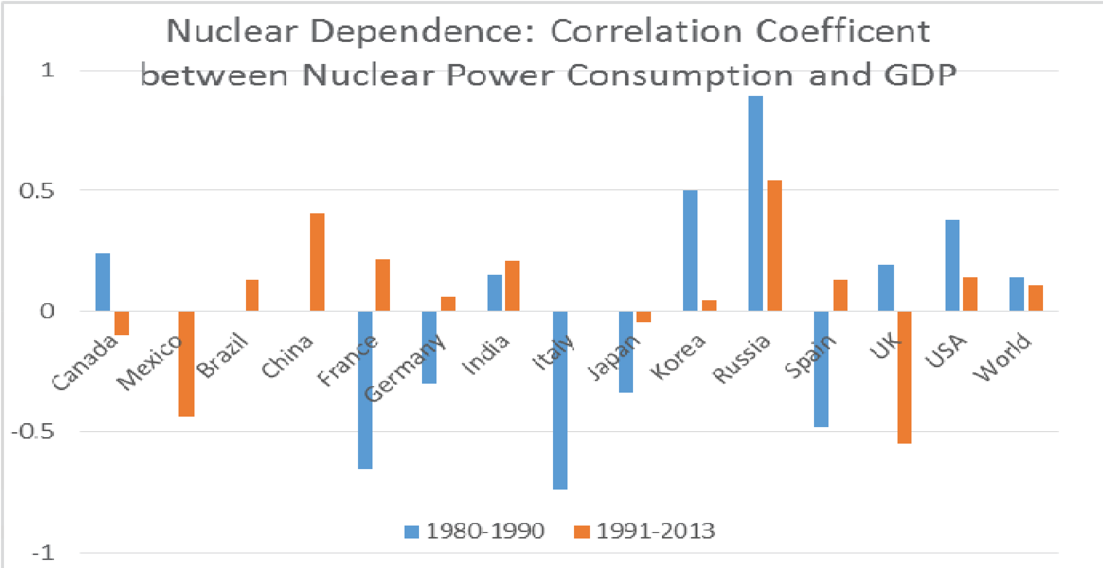

Figure 18. Nuclear Dependence: Correlation Coefficient between Nuclear Power Consumption and Real GDP of Major Economies in 1980-1990 vs. 1991-2013, Sources: BP 2014, USDA 2014

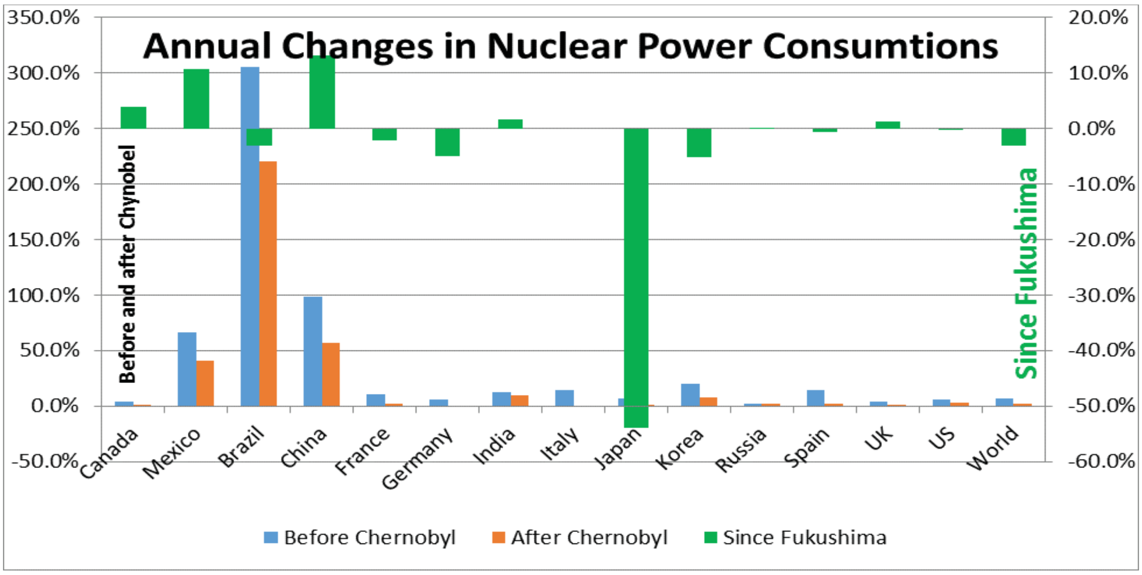

Figure 19. Impacts of Nuclear Disasters on Nuclear Power Consumption, Sources: BP 2014

To gauge the impacts of the nuclear disasters in Chernobyl and Fukushima on nuclear power consumptions of the major economies, this study examined the annual changes in nuclear power consumptions before and after the Chernobyl disaster and since the Fukushima disaster. The results of the investigation, as displayed in Figure 19, indicated that the Chernobyl disaster had affected all major economies' nuclear power consumptions to different extents, from Italy's elimination of nuclear power consumption and Germany's reduction of nuclear power to other major economies' reduced growth rates of nuclear power consumptions. The investigation also showed that the Fukushima nuclear disaster more negatively impacted major economies' nuclear power consumptions. For example, the nuclear power consumptions in China, Mexico, and India significantly reduced their growth rates from around 57 percent, 41 percent and 9.8 percent to around 13 percent, 11 percent and 2 percent respectively; those in Russia and the United States reached a standstill; and those in Japan, South Korea, German, Brazil, France and Spain presented negative growths of around 54 percent, 5 percent, 5 percent, 2 percent and 1 percent respectively. With its higher growth rate of 3.8 percent since the Fukushima nuclear disaster versus that of 1.5 percent after Chernobyl disaster, Canada became the only economy whose nuclear power consumption was less impacted after the recent nuclear disaster than the previous one.

Furthermore, the large-scale ceasing of operation of nuclear power plants in the wake of the Fukushima nuclear disaster in Japan led to sharp decline in Japan's nuclear share from 8 percent in 2011 to less than 1 percent in 2013 and Germany's nuclear share from 8 percent in 2011 to 6.77 percent in 2013. The related fundamental shift in public perception of nuclear safety and security related to reactor accidents, radioactive waste, and other potential problems, prompted Germany to decide to close all its reactors by 2022, Italy to ban new reactors (Westall and Dahl 2013), and the IEA (2012) to halve its estimate of additional nuclear generating capacity to be built by 2035.

Therefore, although nuclear power as a non-carbon energy presents an attractive solution to reducing CO_2 emissions and related global warming for highly carbon dependent major economies, the past pitfalls and future potential concerns related to nuclear safety and security require that considerable improvements in secure and economic technologies be achieved before it can be accepted as a safe, secure and reliable replacement of carbon-based fossil fuels.

In this regard, research and experiments on thorium with molten salt fast reactors as an alternative nuclear fuel to uranium seems to indicate an attractive alternative solution of nuclear energy. Its abundant availability might help meet the energy needs to both support further economic growth and displace fossil fuels on the one hand and its lower radioactivity might help resolve the existing uranium-based nuclear power's environmental and security concerns in terms of nuclear waste disposal and nuclear weapon proliferation (Elsheikh 2013, Heuer et al. 2014, Lin et al. 2013, Ritsuo 2013, Rouch et al. 2014, Schaffer 2013, Serp et al. 2014).

5. Conclusions

Based on an analysis of the major economies' energy consumption, this study reviewed the data of their fossil fuel consumption in the past and examined their carbon dependences, carbon emissions, and the trends of their energy consumption in terms of reducing carbon dependences and carbon emissions. The exploration in the historical carbon-dependent economies provided insights into their strengths and weaknesses in dealing with the carbon challenges, and provides potential keys to understanding the needs of the energy transformation in the major economies.

More specifically, the study examined fossil fuel and nuclear power consumptions of major economies. The ten-year time series data of the oil consumption of the world's four largest economies—the United States, China, Japan and Germany—and the rest of the world and the 46-year time series data of the coal consumption of the world's five largest economies—the United States, China, Japan, Germany and India, were investigated. In addition, the study explored these major economies' natural gas shares, nuclear dependences, energy intensities and carbon intensities in relation to their respective populations and GDPs.

Through this data analysis, the study found common group patterns of oil and coal dependences for both the developed countries and the developed countries as well as exceptions to these common group patterns. While developed countries moved away from coal dependence to oil, gas, and nuclear dependences, the developing countries were still largely stuck with heavy coal dependences. Exceptions to these general group patterns included Germany, which certainly like the other developed economies moved away from its coal dependence, but also decoupled its economy from its original oil dependence and planned determinedly to move away from its nuclear dependence. These findings illuminate different economic, environmental, and ecological challenges of the respective fossil fuel dependences for different development groups on one hand, and on the other hand policy implications of the exceptions to the fossil fuel dependence. Because the developed economies, especially the United States, consumed much more energy, especially oil, per capita, their high oil dependences made them, as existing studies observed (Blanchard and Gali 2007, Anderson 2009, Blinder and Rudd 2009, Hamilton 2009, Theramus 2009, Glaeser et al. 2010, Sexton et al. 2012), extremely vulnerable to soaring oil prices and oil crises which posed high risks to their economic performances. Since the major developing and transitional economies, especially China, were stuck with cheap yet much more polluting coal, their high coal dependences, high energy intensities and high carbon intensities made them extremely susceptible to environmental pollution and related health challenges, which posed high risks to their economic, social, and political development.

These insights have significant contrasting policy implications. The developed countries need to focus their energy policies on reducing energy consumptions per capita, carbon emissions per capita, and oil dependences by accelerating energy transformation ("Energiewende") and further improving energy efficiency. The developing and transitional countries need to focus their energy policies on reducing environmental pollution, coal dependences, energy intensity, and carbon intensity by significantly improving energy efficiency and meeting their increased energy needs through renewable energy.

In this regard, the exception Germany represented to the developed country pattern have positive policy implications for the world economy. The achievements of Germany in economic development with relatively low fossil fuel dependence, low coal dependence, and reduced carbon emissions set good examples for both the developed countries in terms of reducing oil dependence and the developing countries in terms of reducing coal dependence.

The exploration into the major economies' development of unconventional natural gas and nuclear energy production provide some interesting revelations. It showed on the one hand that the deployment of these technologies was still a dividing line between the developed economies and the developing economies. On the other, it indicated while both shale gas and nuclear energy could be developed as alternative energy sources to displace more carbon-intensive fossil fuels such as coal or oil, their past, present and future environmental risks caused and will further cause substantial concerns in affected economies, which prevented and will further prevent them from being developed in large scale as environmentally reliable, trustworthy and sustainable "transitional" alternative energy sources.

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Petrişor A.-I. (2015), *Imperfect health: the medicalization of architecture (book review)*, IAFOR Journal of Sustainability, Energy and the Environment **2(1)**:99-102.

IMPERFECT HEALTH: THE MEDICALIZATION OF ARCHITECTURE (EDITED BY BORASI AND ZARDINI, LARS MÜLLER PUBLISHERS, ZURICH, SWITZERLAND, 2012, ISBN 978-3-03778-279-8)

Alexandru-Ionuţ Petrişor, PhD, PhD, Habil.[1]

Transdisciplinarity is an essential condition for studying and designing the human habitat, from the spatial planning of large territories to civil engineering details, including urban and architectural planning (Petrişor 2013). Its importance is crucial to understanding and deriving sound solutions to a very important nexus governing the life of inhabitants: social issues – environmental constraints – health and welfare. The issues are not new; it is sufficient to recall Dr. John Snow's study of 1854 cholera outbreak in London, or the even older roots of the word 'malaria', suggesting a connection between the presence of this disease and breathing some 'bad air'. Both examples suggest what

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epidemiologists consider an essential principle – the connection between place (and living conditions) and human health. The new additions concern environmental issues; humans altered the environment, and the altered environment turns against those who damaged it. Examples include smog, asthma due to pollution, water which is no longer safe for drinking or heat islands. There are also social issues: increasing urban population, aging population (which, even though living longer, faces more problems, including medical ones), social exclusion and many others.

A vast literature exists on each individual piece of the puzzle. Its largest part deals with designing hospitals and other health care facilities (Taylor 1991, Nesmith 1995, Scher 1996, MacNaughton et al 2007), but other authors describe in more depth the conformation of architecture with the needs of particular categories, such as the elderly (Jara et al 2009), particularly those confronting diseases and medical conditions (Schwarz and Brent 1999). For the latter and in the particular case of Sweden, design is taken further to the urban scale, to stress out the importance of green spaces for their life (Stigsdotter 2005). Other authors look at the architectural needs of cigarette smokers (Zhang et al 2006), or, in more general terms, at architectural dimensions, including interior design, which affect human health (Evans and McCoy, 1998). Conformation with environmental criteria is discussed under the sustainability framework (Lyubomirsky et al 2005), or in particular relationship with the new requirements of the European Union (Edwards, 1996). The common characteristics of these studies are that each one is carried out from a particular viewpoint (environmental psychology, medicine or epidemiology, planning and design, sociology etc.), and addresses a particular issue, filling in a small gap. A huge effort is required in order to put the pieces together in a hole and understand the entire nexus.

An attempt in this direction is '*Imperfect health: The medicalization of architecture*', edited by Giovanna Borasi and Mirko Zardini (with essays by Margaret Campbell, Nan Ellin, David Gissen, Carla C. Kairns, Linda Polak, Hillary Sample, Sarah Schrank and Deanne Simpson), published by Lars Müller Publishers in Zurich, Switzerland in 2012. 399 pages of text and many full color illustrations discuss al the aforementioned issues, and many others: the city as a body (sick or healthy, with consequent effects over its dwellers), nature (as a cure or source of diseases, when man intervenes over it), allergic landscapes and environments, tuberculosis (and associated lifestyle and architecture), emergency urbanism and architecture, role of social interactions (and their urban and architectural requirements), sedentary culture and aging population (along with their planning and design demands) and many other issues are thoroughly discussed and exemplified.

'*What this book is about*'. The book was designed to accompany the exhibition with the same title hosted by the Canadian Centre for Architecture during 25 October 2011 – 15 April 2012 and extend the research presented within the eight chapters with different authors: '*Demedicalize architecture*' (Giovanna Borasi & Mirko Zardini), '*Allergic landscapes, built environments and human health*' (Carla Keirns), '*A theory of pollution for architecture*' (David Gissen), '*Strange bedfolds: Modernism and tuberculosis*' (Margaret Campbell), '*Emergency urbanism and preventive architecture*' (Hilary Sample), '*Your city yourself*' (Nan Ellin), '*Architecture as infrastructure for interactiv-*

ity' (Linda Pollak), 'Gerotopias' (Deane Simpson), and '*Sunbathing in suburbia: Health, fashion and the built environment*' (Sarah Schrank).

The book could easily be used as a study guide. To facilitate this possibility, key words are underlined everywhere throughout the book, including the text and image captions. Examples and illustrations are part of the learning process. A future designer will be able to find sufficient elements allowing her or him to build up sustainable habitats.

'*What this book is not about*'. It is certainly not a cookbook for the architectural designer or urban planner, even though the ingredients are contained. The book includes all principles and examples needed to design healthy buildings or plan for healthy cities, but does not aim to provide for a panacea or offer general solutions, but instead to ask questions and present uncertainties and contradictions (p. 16). The art of putting all pieces together should belong to the designer.

The book *is* about the results of research, but intended for a broader audience (including researchers, academia – and students with backgrounds or interests in medicine, epidemiology and other health-related subjects, environmental sciences, planning and design, but also a general audience). It reads easily even by those who are not entirely familiar with all topics. While the approach is trans-disciplinary, the jargon of each particular area is avoided, making the text easily readable.

'*What are the key points?*' We live in a society obsessed by health and concerned with environmental issues (p. 15), which has damaged its ambient (p. 17). Therefore, we attempt to regenerate the urban body (p. 18) and create fit buildings (p. 28). 'Green' may be a positive solution (pp. 19, 366) for cities. Moreover, in our ageing (pp. 31, 347), segregated (p. 36) and sedentary (p. 253) society, but with longer life expectancy (p. 35), social interactions can help burning calories (pp. 31, 267, 281). The key is a human habitat designed for humans (p. 257), similar to the 'cities for people' (Gehl 2010).

In more details, the quality of human habitat must account for health issues from the architectural details to the entire city; we are the ones to design healthy or sick cities (p. 231) or buildings (p. 251). Sick buildings can trigger heart attacks and stroke (p. 251). Among the urban diseases, allergies (pp. 97-98) are the most important, leading to asthma and tuberculosis (pp. 99-101). Buildings and cities must prevent allergies and reduce their effects. The process must start with our home, where mites and cockroaches trigger allergies (p. 110). However, the main cause is pollution (p. 117), including indoor cigarette smoking (p. 128), and designers must account for it. In addition, special design criteria are required for tuberculosis, applicable to interior (pp. 146-149), architectural (pp. 139-145) and urban (pp. 135-136) design, but also to special facilities (pp. 137-138). The menace of urban epidemics points to the choice of isolation vs. quarantine in order to defend the city (pp. 234-238).

The take-home message is that proper design, which is in our hands, could be the solution for mitigating the effects of an altered environment against us and better off the social climate. The tools exist, but there is a strong need for thinking ahead over the people when starting the design process, be it for a single building or entire city. Nevertheless, in order to be successful, the design process must be de-medicalized.

Overall, the book is successful in completing the puzzle needed to understand the social – environmental – health nexus, illustrating each possible relationship in both ways (*e.g.*, influence of environmental conditions on human health in the city, but also a healthy design, able to encompass the natural environment for bettering off health or mitigate the harmful consequences of pollution and warming climate). At the same time, it provides *solutions* in each case, and from this perspective represents a 'must read' for a future planner or designer.

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IAFOR Journal of Sustainability, Energy and the Environment
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Author Guidelines

AUTHOR GUIDELINES

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(b) Reference list

(i) Books: Surname, Initial. (Year), *Title*, Publisher, Publishing Company's Nearest Headquarters (e.g. London): Douglas, M. & Watson, C. (1984), *Networking*, Macmillan, London.

(ii) Chapter in edited books: North, D. (1980), 'Energy use at home', in *Energy Conservation*, eds S. Scott & N. Peel, Academic Press, London.

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(x) Other Internet resources needs to specify the type of medium, in square brackets (it should almost always be [Online]), the full URL, which indicates the type of online medium, e.g., WWW (rarely ftp or gopher), the date that the item was accessed, since electronic documents are often updated, and the size of the document, e.g., pagination if that is known; labelled part, section, table etc; or size of the file.

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Compliance with the Author Guidelines is compulsory for publication. The editorial checking process occurs after the acceptance of papers by reviewers. Despite of their acceptance, papers can be rejected if, after three successive editing rounds, editing mistakes are still present.

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