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Population Dynamics, Environmental Sustainability and Governance: A Framework for Population Footprints

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INTRODUCTION

"If all mankind were to disappear, the world would regenerate back to the rich state of equilibrium that existed ten thousand years ago. If insects were to vanish, the environment would collapse into chaos": **Edward O. Wilson**

The interrelationship between human population growth and global carrying capacity has been well discussed, examined and debated in the academic literatures. This relationship is complex, multidimensional and has different patterns at global and regional levels.

In 1991, Garrett Hardin argued that energy is the common coin in which all competing demands on the environment can be measured. But Wackernagel and Rees (1996) have introduced the concept of, and method for calculating the *Ecological Footprints*. It is presented as a simple operational indicator to assist in monitoring progress towards (un)sustainability, i.e. maintenance (loss) of natural capital. It accounts for the flows of energy and matter to and from a specific economy or activity, converted into corresponding land and water area needed to support these flows. Six land categories are included in the procedure, namely consumed/degraded land (built environment), gardens, crop land, pasture land and grasslands, productive forest, and energy land.

Ecological footprints analysis is suggested to be useful in determining the human appropriation of ecological production, measured in area units. The power of the method is the fact that all human exploitation of resources and environment is reduced to a single dimension, namely land and water area needed for its support. An EF can be assessed for persons, activities or regions (van den Bergh and Verbruggen, 1998).

Wackernagel and Rees also calculate the EF/actual-productive-area ratio for a region, as an indication of its (un)sustainability. Especially small developed countries and densely populated cities score high on this ratio measure: for instance, Belgium and the Netherlands between 10 and 20; and London 120. In addition, one can compare per capita EFs with the per capita available ecological space on Earth. It is estimated that the latter has decreased from approximately 6 to 1.5 hectares since the beginning of the century (van den Bergh and Verbruggen, 1998).

According to Cohen (1995), "over the last 2000 years, the annual rate of increase of global population grew about 50-fold from an average of 0.04% per year between AD". Human influence on the planet has increased more rapidly than the total human population. For many people, human action is linked to an unprecedented speech of environmental problems (Demeny, 1991), some of which affect human well-being directly. The future of the human population, like the futures of its economies, environments, and cultures, is highly unpredictable. The United Nations (UN) regularly publishes projections that range from high to low. There is much more uncertainty about the demographic future than such projections suggests (Stoto, 1983).

Cohen (1996) also argued that calculations of estimates of Earth's maximum supportable human population use one of six methods, apart from those that are assertions without data. First, several geographers divided Earth's land into regions, assumed a maximum supportable population density in each region, multiplied each assumed maximum population density by the area of the corresponding region, and summed over all ·regions to get a maximum supportable population of Earth. The assumed maximum regional population densities were treated as static and were not selected by an objective procedure. Second, some analysts fitted mathematical curves to historical population sizes and extrapolated them into the future (Pearl & Reed, 1924). As the causal factors responsible for changes in birthrates and death rates were, and are, not well understood, there has been little scientific basis for the selection of the fitted curves. Third, many studies focused on a single assumed constraint on population size, without checking whether some other factors might intervene before the assumed constraint comes into play. The single factor most often selected as a likely constraint was food. Fourth, several authors reduced multiple requirements to the amount of some single factor. Other factors that cannot be reduced to an area of land, such as water or energy, are sometimes recognized indirectly as constraints on the extent or productivity of cultivable land. The authors who combined different constraints into a single resource assumed that their chosen resource intervened as a constraint before any other factor.

Fifth, several authors treated population size as constrained by multiple independent factors. Westing in 1981 estimated the constraints on population imposed independently by total land area, cultivated land area, forest land area, cereals, and wood. Sixth and finally, several authors have treated population size as constrained by multiple interdependent factors and have described this interdependence in system models. System models are large sets of difference equations (deterministic or stochastic), which are usually solved numerically on a computer. System models of human population and other variables have often embodied relations and assumptions that were neither mechanistically derived nor quantitatively tested.

Since the formulation of the ecological footprint, a number of researchers have criticised the method as originally proposed (Levett 1998; van den Bergh and Verbruggen 1999; Ayres 2000; Moffatt 2000). The criticisms largely refer to the oversimplification in ecological footprints of the complex task of measuring sustainability of consumption, leading to comparisons among populations becoming meaningless[1], or the result for a single population being significantly underestimated. In addition, the aggregated form of the final ecological footprint makes it difficult to understand the specific reasons for the unsustainability of the consumption of a given population (Rapport 2000), and to formulate appropriate policy responses (Ayres 2000). While generally acknowledged as a valuable educational tool, the original ecological footprint is not seen as a regional policy and planning tool for ecologically sustainable development, because it does not reveal where impacts really occur, what the nature and severity of these impacts are, and how these impacts compare with the self repair capability of the respective ecosystem. In response to the problems highlighted, the concept has undergone significant modification (Ferng 2001, Lenzen and Murray 2001). Development of and debate about the method are continuing.

From the above perspectives, this paper is an attempt to construct a summary measure for population dynamics and thereby a further attempt has been taken to understand the linkages among population-resource-environment nexus with the help of this new summary measure called 'Population Footprints'. Finally, a framework has been proposed to explain this complex interrelationship among population, environment and governance.

OBJECTIVES

- ❖ To study the levels and linkages among environmental system, environmental stress, population dynamics, social and institutional capacity by countries.
- ❖ To construct a composite index for 'population footprints' as a summary measure.
- ❖ To develop a final framework to show the interrelationships among present population footprints, future environmental sustainability and role of governance.

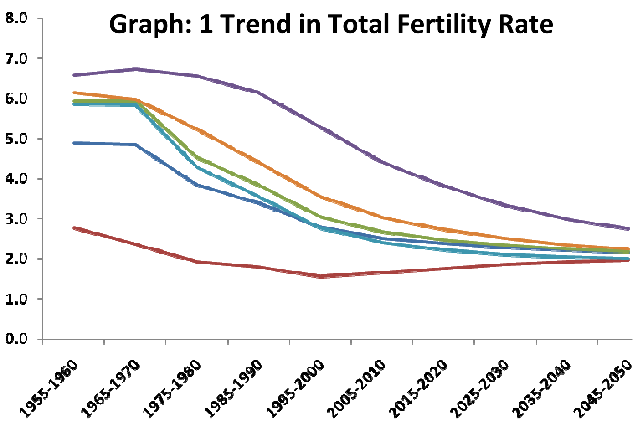
DATA AND METHODOLOGY

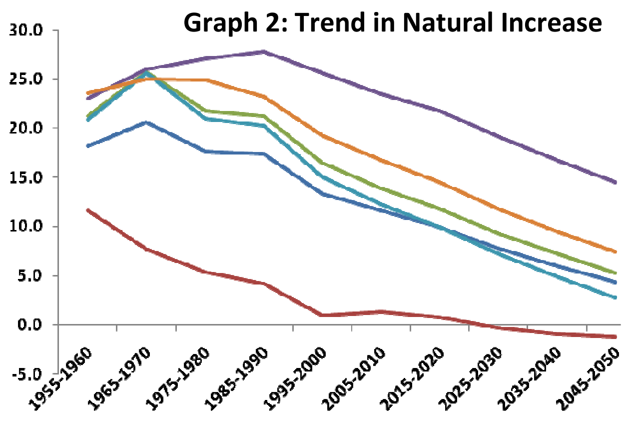
Data have been used from United Nations Population Prospects 2010, United Nations World Contraceptive Use 2010, Environmental Sustainability Index 2005 and Environmental Performance Index 2010, published by Yale Centre for Environmental Law and Policy (YCELP), Yale University and Centre for International Earth Science Information Network (CIESIN), Columbia University. Data for 144 countries have been included in the analyses.

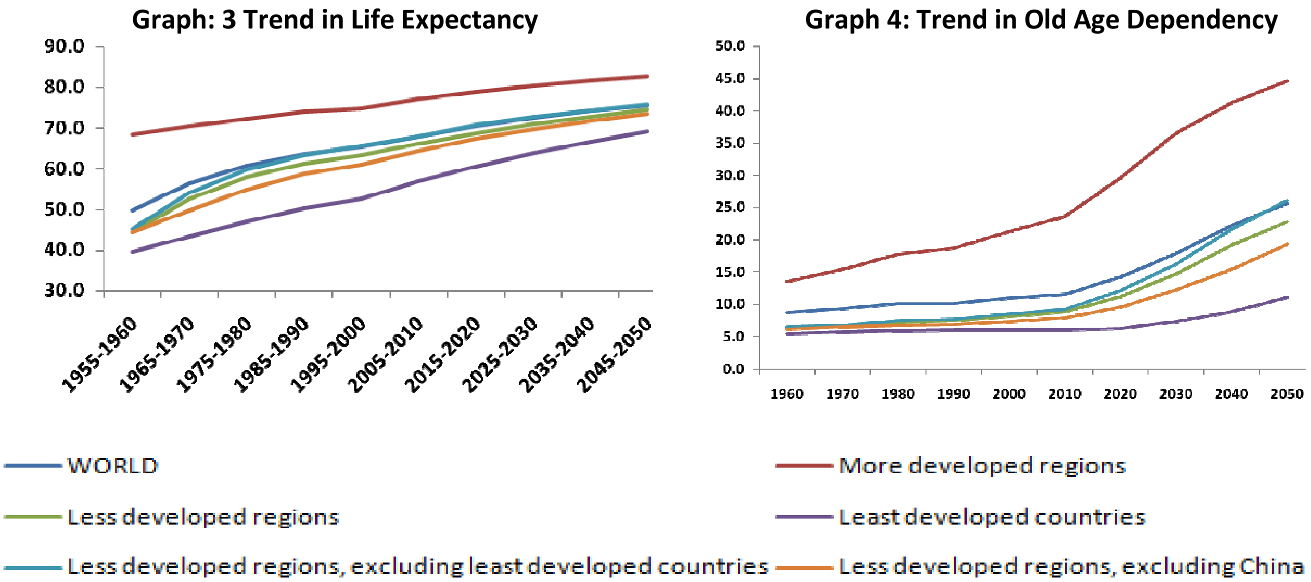
Levels and Linkages have been examined by mean, bi-variate cross-tabulation, Pearson correlation and simple linear regression. A summary measure of population footprints have been constructed though principal component analysis and path analysis has been carried out to propose the framework.

FINDINGS

A. POPULATION DYNAMICS







Indicators of population dynamics have clear spatial patterns and marked differentiations exist in all four indicators. Figure 1 to figure 4 give the population dynamics in the world and in different countries by their levels of economic development. Population dynamics in the region have been shown by trend analysis of four indicators: total fertility rate, natural increase, life expectancy and old age dependency from 1955 to 2050. The trend in all four indicators of population dynamics have been projected till 2050. So, the past performance, present progress and future development can be examined. Graphs show that though the huge gap in levels of TFR has been reducing between less developed and more developed countries in the world, but it will still remain in the future. The less developed countries will have TFR above replacement level and it would be serious concerns for overall development of these countries.

Regarding the natural increase, more developed countries will experience negative population growth in future, but the rate of natural increase will be very high among least / less developed countries, though the rate of natural increase has been decreasing in these countries since 1990. The levels of life expectancy have been increasing since 1955 in all countries but the rate of increase is different by development level. By 2050, the life expectancy will be supposed to reach at more than 80 years in developed countries where as life expectancy in least developed countries will be supposed to be at around 60 years which would be still lower from the life expectancy achieved by developed countries in 1955. Old age-dependency rate will be strikingly increased in more developed countries and huge gap in old age population will exist between least developed and more developed countries by 2050.

B. ENVIRONMENTAL SUSTAINABILITY SCENARIO

"After all, sustainability means running the global environment - Earth Inc. - like a corporation: with depreciation, amortization and maintenance accounts. In other words, keeping the asset whole, rather than undermining your natural capita": Maurice Strong

In this paper, environmental sustainability has been examined in terms of ecosystem vitality, environmental systems, environmental stress, reducing environmental stress and overall environmental sustainability index. Ecosystem Vitality is a summary measure relevant to the goal of reducing the loss or degradation of ecosystems and natural resources (*EPI 2010,* YCELP and CIESIN).

Table 1: Ecosystem vitality indicators and their significance in sustainability study

Resources	Significance	Indicators
Biodiversity	Protecting biodiversity ensures that a wide range of "ecosystem services" will remain available for current and future generations.	Biome Protection Marine Protection Critical Habitat Protection
Forestry	The forestry metric highlights the importance of forests as a global resource as well as the need for more robust international monitoring efforts.	Growing Stock Exchange Forest Cover Change
Fisheries	Overfishing of species can be disastrous to marine biodiversity and ecosystem stability and fisheries are also an important part of many countries' economies.	Marine Trophic Index Trawling Intensity
Agriculture	As agriculture depends so heavily on a country's natural resources (soil, water, and climate), growing populations and changes in diet, increase pressures on productive systems. Agriculture is not just an environmental issue. It is a developmental, health, and economic issue, as well.	Agricultural Water Intensity Agricultural Subsidies Pesticides Regulation

Source: EPI 2010, YCELP and CIESIN.

Table 2: Sustainability indictors by countries with different levels of development

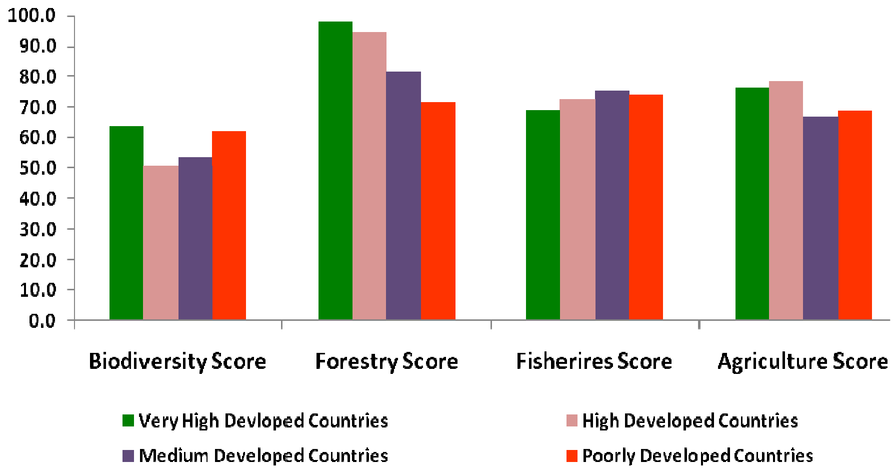
Countries by Development	Ecological Footprints Per Capita (Hectares of Biologically Productive Land Required per Capita)	Percentage of Total Land Area Having Very High Anthropogenic Impact	Freshwater Availability Per Capita in Thousand Cubic Meters	Internal Groundwater Availability Per Capita in Thousand Cubic Meters
Very Highly Developed Countries	5.21	10.35	24.39	5.25
Highly Developed Countries	2.70	3.76	25.99	2.85
Medium Developed Countries	1.71	2.55	43.77	6.61
Poorly Developed Countries	1.02	0.52	18.29	2.79

Source: Author's analyses and YCELP and CIESIN 2005, 2010

Table 2 gives a glimpse of sustainability issues by countries with different development levels. The ecological footprints and anthropogenic impact are highest among countries with very high development level and lowest among countries with poor development. But yet the very highly and highly developed countries still have better reserve of water than poorly developed countries. But it is the medium developed countries which have shown apparently better position in terms of water sustainability. Ecological footprints and anthropogenic impact are lower among these countries in comparison to highly developed countries and also the mean fresh water availability per capita has been found to be highest among this group of countries.

Graph 3 will examine the sustainability issues through environmental vitality scores by countries with different degrees of development. Graph shows that high and medium developed countries are relatively poor performers in terms of biodiversity scores in comparison to very high and poorly developed countries. Regarding forestry, the scores is negatively associated with degree of development. Poorly developed countries have exploited forest resources heavily and create a serious concern for them. On the other hand, relatively low fisheries score has been observed among very highly developed countries and lowest agriculture score has been found to be among medium developed countries.

Graph 3: Environmental Vitality Indicators by Levels of Development



Environmental sustainability is complex and hard to define. In this paper, the levels of environmental sustainability has been examined by 'Environmental Sustainability Index 2005' developed by YCELP and CIESIN, the Environmental Sustainability Index suggests that sustainability has multiple dimensions – and distinct challenges for developed versus developing countries. Environmental Sustainability Index is based on 5 components (Environmental Systems, Reducing Environmental Stresses, Reducing Human Vulnerability, Social and Institutional Capacity and Global Stewardship), 21 indicators and 76 variables. The Environmental Sustainability Index (ESI) benchmarks the ability of nations to protect the environment over the next several decades. The most important function of the Environmental Sustainability Index is as a policy tool for identifying issues that deserve greater attention within national environmental protection programs and across societies more generally. The Environmental Sustainability Index also provides a way of identifying those governments that are at the leading edge with regard to any particular issue.

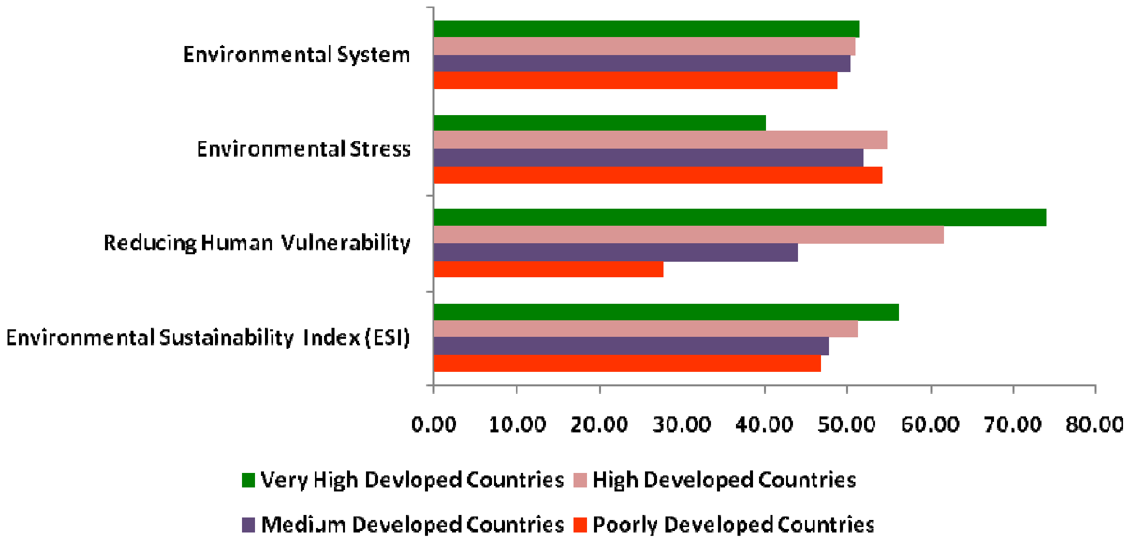
Table 3: Environmental sustainability indicators

Sustainability Components	**Significance**	**Indicators**
Environmental Systems	A country is more likely to be environmentally sustainable to the extent that its vital environmental systems are maintained at healthy levels, and to the extent to which levels are improving rather than deteriorating.	Air Quality, Biodiversity, Land, Water Quality, Water Quantity
Reducing Environmental Stresses	A country is more likely to be environmentally sustainable if the levels of anthropogenic stress are low enough to engender no demonstrable harm to its environmental systems.	Reducing Air Pollution, Reducing Ecosystem Stress, Reducing Population Pressure, Reducing Waste and Consumption Pressure, Reducing Water Stress and Natural Resource Management
Reducing Human Vulnerability	A country is more likely to be environmentally sustainable to the extent that people and social systems are not vulnerable to environmental disturbances that affect basic human wellbeing; becoming less vulnerable is a sign that a society is on a track to greater sustainability.	Environmental Health, Basic Human Sustenance and Reducing Environment-Related Natural Disaster Vulnerability

Source: ESI 2005, YCELP and CIESIN.

Graph 4 depicts that except for the environmental stress factor, the poorly developed countries will have serious sustainability issues in future. Human vulnerability scores have been found to be highest among this group of countries as well as environmental systems have also been badly maintained. The overall sustainability index is found to be lowest among poorly developed countries. Developed countries must find ways to manage the environmental stresses of industrialization and consumption of natural resources, particularly those that are non-renewable. Developing countries face the risk of depleting renewable resources such as water and forests as well as the challenges of funding investments in environmental protection and creating functioning institutions that permit economic growth and support appropriate regulation.

Graph 4: Components of Sustainability



C. POPULATION FOOTPRINTS AS SUMMARY MEASURE

"Malthus has been buried many times; and Malthusian scarcity with him. But as Garrett Hardin remarked, anyone who has to be reburied so often cannot be entirely dead": Herman E. Daly, 1977

In the preceding segment, the linkages between environmental sustainability and levels of development have been explored. In this section, the relationships between population and environmental sustainability have been examined. TFR, rate of natural increase per 1,000 population, under 5 mortality rate, life expectancy at birth, usage of any methods of contraception have been taken as indicators of population dynamics. A correlation matrix has been carried out among population dynamics indicators and environmental sustainability indicators to examine inter-linkages among the variables. Results show that not all aspects of population dynamics are related in the same way with the environmental indicators. Demographic aspects like total fertility rate, natural increase and under 5 mortality have significant positive correlation with environmental stress and have significant negative correlation with agriculture, forestry, ecological footprints and overall sustainability. These findings establish the fact that higher population growth increases environmental stress as well as decline the sustainability levels in agriculture, forestry, ecological footprints and overall sustainability. On the other hand, positive (indicator of development) indicators of population dynamics like life expectancy at birth and usage of contraception do have significant positive correlation with resources as well as overall sustainability. Obviously, these population indicators are found to be significantly negatively associated with environmental stress.

Table 4: Correlation among population dynamics indicators and environmental sustainability indicators

Demographic Factors	**Results from Correlation Matrix**	
	Significant Positive Correlation	**Significant Negative Correlation**
Total Fertility Rate, Rate of Natural Increase per 1,000 Population, Under 5 Mortality Rate	Environmental Stress	Agriculture, Forestry, Ecological Footprints and Overall Sustainability
Life Expectancy at Birth, Usage of Any Method of Contraception	Agriculture, Forestry, Ecological Footprints and Overall Sustainability	Environmental Stress

Source: Author's analyses

In nutshell, present resource consumptions and future environmental sustainability is related to present demographic situations in a country or in a region. Undoubtedly, population dynamics has significant impacts on resources-environment. Moreover, not all aspects of population dynamics are affecting the future environmental sustainability of a country or in a region in the same direction and also the degree of impacts of the different indicators of population are also different on environment. Hence, there is a need to have a summary measure of population which will represent the overall population burden on resource-environment. This summary measure may be called as 'Population Footprints'. In the present paper, PCA have been carried out to build one composite index for 'population footprints' which will explain the overall population burden on resource-environment in a given country or in a region. The population footprints thus obtained has been categorized into five levels: very low, low, medium, high and very high. The very low population footprints indicate the lower burden of population dynamics (including all its characteristics) whereas very high population footprints are a sign of higher overall population burden in a region.

Table 5: Population Footprints and Levels of Development

Population Footprints (Degree of Impact on Environment and Resources)	**Percent Distribution of Countries with Levels of Development**			
	Very High	**High**	**Medium**	**Poor**
Very Low	79.31	17.24	3.45	-
Low	25.00	53.57	21.43	-
Medium	3.70	59.26	37.04	-
High	-	6.90	51.72	41.38
Very High	-	-	7.14	92.86

Source: Author's analyses

Table 5 shows percentage distribution of countries by levels of population footprints. Very high population footprints have been found in poorly developed countries and very low population footprints are found to be mostly characteristics of highly developed countries. These also vote for the usefulness of this index as this index validates the fact that low population burden is characteristic feature of high development. Now, correlation and linear regression analyses have been carried out to examine the linkages between population footprints and other environmental indicators. The results of the analyses have been presented in table 6.

Table 6: Relationships between population footprints and other resource-environmental indicators

Resource and Environmental Indicators	**Pearson Correlation Coefficient**	**Adjusted R^2 From Regression Analysis**
Agriculture	-0.289***	0.077***
Forestry	-0.440***	0.188***
Ecological Footprints per capita	-0.585***	0.337***
Environmental Stress	0.275***	0.069***
Environmental Sustainability Index	-0.350***	0.122***

*** Significant at 1% level
Source: Author's analyses

Results prove that high population footprints have are significantly negatively associated with agriculture, forestry, ecological footprints and overall environmental sustainability with positive impact on environmental stress. This finding signifies and validates that high population footprints have adverse effects on present day agriculture, forestry or other resources. Environmental stress is higher among this group of countries and achieving sustainability in future is also difficult for these countries if the present demographic situations continue.

D. GOVERNANCE AND POPULATION FOOTPRINTS

"It is time for the world, the hemisphere and the region to make sure that relevant institutions of civil society and relevant laws are embedded in the mechanisms of governance": Baldwin Spencer

Table 7 exhibits the relationship between governance and population footprints. Levels of good governance in a country have been measured by two indicators - social and institutional capacity and environmental governance. These indicators have been obtained from YCELP and CIESIN.

Social and Institutional Capacity has been defined as if a country is more likely to be environmentally sustainable to the extent that it has in place institutions and underlying social patterns of skills, attitudes, and networks that foster effective responses to environmental challenges. This component is proxy for Good Governance and is based on indicators like Environmental Governance, Eco-Efficiency, Private Sector Responsiveness and Science and Technology.

Environmental Governance is part of Social and Institutional Capacity and is based on following variables: ratio of gasoline price to world average, corruption measure, government effectiveness, Percentage of total land area under protected status, World Economic Forum Survey on environmental governance, rule of law, Local Agenda 21 initiatives per million people, civil and political liberties, IUCN member organizations per million population, knowledge creation in environmental science, technology, & policy and democracy measure.

Table 7: Levels of governance by population footprints

Population Footprints	**Mean Scores**	
	Social and Institutional Capacity	**Environmental Governance**
Very Low	73.55	0.92
Low	52.65	0.10
Medium	40.43	-0.25
High	37.94	-0.43
Very High	35.31	-0.49

Source: Author's analyses

Table 7 shows that population foot prints is negatively associated with environmental governance and social and institutional capacity which can be used as indicator of good governance. High population footprints have low social and institutional capacity and vice versa. Environmental governance has been found to be negative in countries with high population footprints. Now, the relationships among governance, environment and population dynamics have been examined through correlation analyses which have been presented in table 8.

Table 8: Governance correlates with environment and population footprints

Indicators	Social and Institutional Capacity	Environmental Governance
Ecological Footprints Per Capita	0.629***	0.651***
Environmental System	0.098	0.089
Environmental Stress	-0.458***	-0.471***
Environmental Sustainability Index	0.683***	0.621***
Population Footprints Scores	-0.583***	-0.568***

*** Significant at 1% level

Source: Author's analyses

Findings show that good governance is significantly positively associated with ecological footprints and overall environmental sustainability but significantly negatively related to environmental stress and population footprints. This implies that higher the population burden, lower the good governance and vice versa.

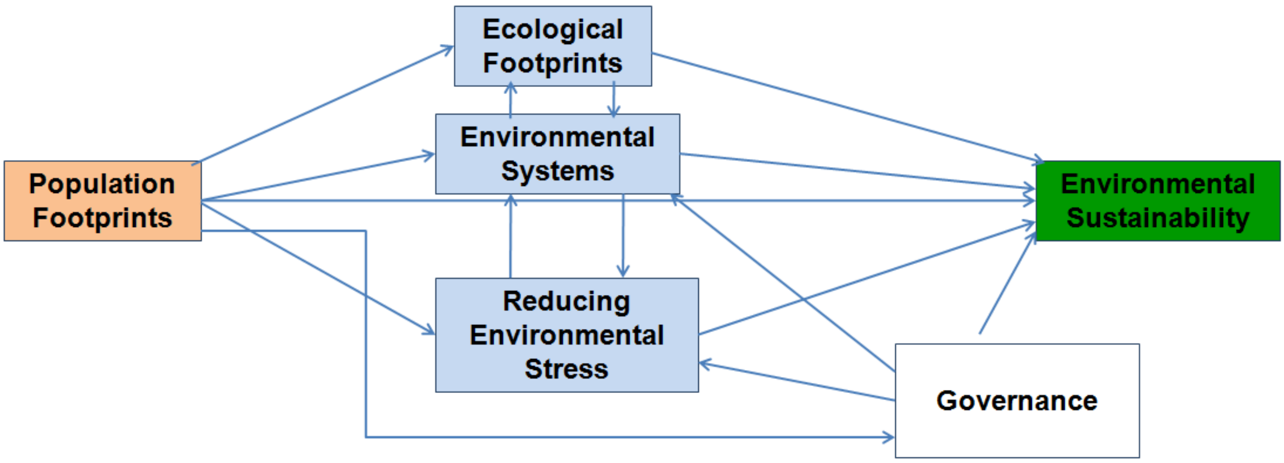
E. FRAMEWORK

"Every theory is a self-fulfilling prophecy that orders experience into the framework it provides": Ruth Hubbard

In the preceding segments, the inter-linkages among population (both with different indicators and with summary measure), environmental sustainability and governance have been examined. On the basis of the inter-linkages among the variables, one path analysis model have been developed using the software AMOS 5 to give a framework for population footprints model (Figure 1).

The model explains that future environmental sustainability is depends on present population footprints of a given country or a region but the good governance will act as a conduit between them and significant changes can be possible to bring through it.

Figure 1: Population Footprints Framework through Path Model



CONCLUSION

"Our society is built not on the joy and happiness of the past, but on the agonies experienced by the long line of our predecessors. Whether or not all the agonies or struggles of the past will emerge into a great future, or will vanish into nothing at all, is likely to be decided in the next few tens of human generations": Fred Hoyle on Everyman's Universe in Ten Possible Worlds

Population dynamics is linked with future environmental sustainability. Developed countries must find ways to manage the environmental stresses of industrialization and consumption of natural resources, particularly those that are non-renewable. Developing countries face the risk of depleting renewable resources such as water and forests as well as the challenges of funding investments in environmental protection and creating functioning institutions that permit economic growth and support appropriate regulation.

Index of Population Footprints also validates this and this index as a summary measure of overall population scenario / burden in a country or a region can be adopted. High population footprints have negative impact on resources and environment and this is significant characteristics of countries where level of development is low. The Framework explains that future sustainability of a region depends on present population footprints and governance works as a conduit between these two factors.

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