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Study of sustainable development using Fuzzy Cognitive Relational Maps (FCM)

A. Victor Devadoss[1] , M. Syed Ismail[2]
[1]PG and Research Department of Mathematics, Loyola College, Chennai, India
[2]Department of Mathematics, The New College, Chennai, India
Email : [1]hanivictor@yamil.com , [2]msismail72@gmail.com

Abstract-Sustainable development provides a framework under which communities can use resources efficiently, create efficient infrastructures, protect and enhance quality of life, and create new businesses to strengthen their economies. It can help us create healthy communities that can sustain our generation, as well as those that follow ours. Sustainable development is not a new concept. Rather, it is the latest expression of a long-standing ethic involving peoples' relationships with the environment and the current generation's responsibilities to future generations. For a community to be truly sustainable, it must adopt a three-pronged approach that considers economic, environmental and cultural resources. Communities must consider these needs in the short term as well as the long term. Sustainable Development also can be defined simply as a better quality of life for everyone, now and for generations to come. It is a vision of progress that links economic development, protection of the environment and social justice, and its values are recognised by democratic governments and political movements the world over. Sustainable Development is therefore closely linked to Governance, Better Regulation and Impact Assessment. Indicators to measure progress are also vital.This paper has four sections. In the first section we introduce the notion of fuzzy cognitive maps and Combined Fuzzy Cognitive Maps (CFCMs). In section two we describe the problem and justification for the use of FCMs. In section three we give the adaptation of FCM to the problem. In the final section we give conclusions based on our analysis of the problem using FCM.

Keywords-Cognitive Maps (FCMs), Combined Fuzzy Cognitive Maps (CFCM) , sustainable development, economic, environmental and cultural resources.

I. BASIC NOTIONS OF FUZZY COGNITIVE MAPS (FCM)

FCMs are the best suited tool in the study and analysis of the unsupervised data. For they are the only structures which can give the hidden pattern of the dynamical system. Let $C_1, ..., C_n$ be n attributes or nodes. Suppose there is some causal flow of relation between the concepts C_i and C_j where $1 \le i, j \le n$, this relation of how much the occurence of C_i influence variations or chagnes in C_j can be described by signed directed graphs with feed back. Fuzzy Cognitive Maps are fuzzy signed directed graphs with feed back. The directed edge e_{ij} from causal concept C_i to concept C_j measures how much C_i causes C_j. The edges e_{ij} take values in the real interval [-1,1]. $e_{ij} = 0$ indicates no causality. $e_{ij} > 0$ indicates causal increase: C_j increases as C_i increases, or C_j decreases as C_i decreases. $e_{ij} < 0$ indicates causal decrease or negative causality that is C_j increases as C_i decreases or C_j decrease as C_i increases.Simple FCMs have edge values in {-1, 0, 1}. If causality occurs, it occurs to maximal positive or negative degree. Simple FCMs provide a quick first-hand information to an expert's stated causal knowledge. We use in this paper only simple FCMs to study the problem. Using the directed graphs we can obtain the causal connection matrix M which is a $n \times n$ matrix with entries from the set {0, 1, -1}. $A = (a_1, a_2, ..., a_n)$ is called a state vector where either $a_i = 0$ or 1. $a_i = 0$ implies the concept C_i is in the OFF state. $a_i = 1$ implies the concept C_i is in the ON state.We pass state vectors C_1 repeatedly through the FCM connection matrix M. An equilibrium in this system is attained when we have a set of repeated patterns. Repeating patterns can be fixed points or limit cycles. A fixed point is a single recurring pattern such as, say, $C_3 \Rightarrow C_3$ in the pattern $C_1 \Rightarrow C_2 \Rightarrow C_3 \Rightarrow C_3$. A 'limit cycle' is a set of multiple repeating patterns such as $C_3 \Rightarrow C_4 \Rightarrow C_5$, $C_1 \Rightarrow C_2 \Rightarrow C_3 \Rightarrow C_4 \Rightarrow C_5 \Rightarrow C_3 \Rightarrow C_4 \Rightarrow C_5$, ... Thus the fixed point or limit cycle is known as the hidden pattern of the system. The state vector is updated and thresholded at each stage. Inference from the hidden pattern summarizes the joint effects of all interacting fuzzy knowledge.

Since the data is an unsupervised one and the study is done using only experts opinion, we to obtain an unbiased analysis of our problem and conclusions use the combined FCM. In combined FCM equal weightages are given to each expert. FCM combination provides a unbiased solution to this problem. We can additively superimpose each experts opinion given as an FCM in an associate - memory fashion, even though the FCM connection matrices $M_1, ..., M_k$ may not be conformable for addition. Combined conflicting opinions tend to cancel out and assisted by the strong law of large numbers, a consensus emerges as the sample opinion approximates the underlying population opinion. By adding these augmented FCM matrices $F_1, ..., F_k$. We permute the rows and columns of the augmented matrices to bring them into mutual coincidence. Then we add the F_i point wise to yield the combined FCM matrix F.

$$F = \sum_i F_i$$

(i.e.,) $F = F_1 + F_2 + F_3 + ... + F_k$

II. DESCRIPTION OF THE PROBLEM AND JUSTIFICATION FOR USING FCM MODEL

Sustainable development has first and foremost been a way of thinking. It has been a normative concept - referring to development goals as a sound environment combined with the necessity of basic needs and social well-being. The challenge lies in the way the concept can be moved from words at conferences and at the policy level – to the action level. Bringing about concrete social, economic and environmental

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change. Therefore, the notion of implementing words through concrete actions necessarily points to the need for concrete implementation tools and measures. There is also a need for identifying people and organizations to adopt targets, measure progress and actually bring about change.

The Plan of Implementation of the World Summit on Sustainable Development states that "Strengthen and promote programmes of the International Labour Organization (ILO) and World Health Organization (WHO) to reduce occupational deaths, injuries and illnesses and link occupational health with public health promotion as a means of promoting public health and education". The OECD's (Organisation of Economic Cooperation and Development) Environmental Strategy adopted by OECD Environment Ministers in 2001 also focuses on the Social Interface: It calls for national action related to health and safety - with a special emphasis on chemicals and hazardous substances. WSSD has reinforced these points and has encouraged a link between occupational and public health, and a link between occupational health and safety with environment

Sustainable Development, as defined by the World Commission on Environment and Development (the Brundtland Commission), is the capacity to meet the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable Development must balance the needs of society, the economy, and the environment Sustainable Development is therefore closely linked to Governance, Better Regulation and Impact Assessment. Indicators to measure progress are also vital.Sustainable Development Indicators (SDI) are various statistical values that collectively measure the capacity to meet present and future needs. SDI will provide information crucial to decisions of national policy and to the general public. The SDI Group has four principle tasks to support the selection of national indicators of sustainable development: Develop a framework to identify, organize, and integrate national sustainable development indicators. This framework will cover all aspects of the Earth system: society, economy, and environment. The framework will support efforts to develop regional and local indicators. Develop an information system providing easy, low cost, electronic access to Federal data and information about sustainable development indicators. Release regular reports on progress toward national sustainable development indicators. Recommend an organizational strategy in which all levels of government, non-government organizations, and industry can collaborate on the long term evolution of sustainable development indicators.
The following are taken as Sustainable Development Indicators (SDI)

C_1Acts of Terrorism and Crime - Number of terrorist acts and Overall crime rate within India Those activities, actions, and operations that involve the interaction between people. This framework element serves as a broad placeholder for all social processes. All subcategories currently emphasize the driving forces that directly act upon an endowment**.**

C_2 Agriculture Land Conversion - Prime agricultural land area converted to urban use per year
All ecosystems modified or created by man specifically to grow or raise biological products for human consumption or use. This includes cropland, pasture, orchards, groves, vineyards, nurseries, ornamental horticultural areas, and confined feeding areas.

C_3 Capital Assets -Total value, in rupees, of India tangible reproducible capital, excluding all public infrastructure, as defined in the National Asset Accounts
Investment in public and private infrastructure to maintain sufficient capacity, research and development, technology innovation.

C_4 Consumption Expenditures Per Capita - Total rupee value of goods and services purchased by consumers per year as defined in the National Income Accounts**.**
Energy used per unit of output, Money spent for exporting technology that is cost-effective and environmentally sound, Export concentration ratio (%), Exports of goods and services , Imports of goods and services , Distribution of income per capita arranged to show the percentage of the population at various levels of income

C_5 Discrimination Cases - Number of caste discrimination cases brought before courts
Unfair or partial treatment of one socioeconomic group by another

C_6 Ecosystem Diversity -: Area of threatened ecosystems organized by type
Undesirable changes in the variety of biota, and ecosystems. Area and percent of forest land with diminished biological components indicative of changes in fundamental ecological processes (e.g. soil, nutrient cycling, seed dispersion, pollination, deforestation)

C_7 Energy Consumption by Use - Total Energy consumed organized by use (construction, transportation, production, heating, etc.)
Changes in the stocks and use of energy resources, such as coal, oil, natural gas, nuclear, hydroelectric reserves.

C_8 Environmental Technology Sales - Total amount of money spent of environmental technology
Amount of Money Spent for Development of environmentally safe or benign technology and money for exporting technology that is cost-effective and environmentally sound

C_9 Faith in Justice - Number of people who believe the court system is fair
The ability of the legal system to quickly and fairly prosecute criminals and dispense justice

C_{10} Groundwater Contamination and Groundwater Drawdown-
Area of land with contaminated ground water and Change in depth of water table over time
Buildup of pollutants, toxins, and heavy metals in water and sediments, changes in the stock, capacity, or use of water resources and Annual withdrawals of ground and surface water as % of available water

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C_{11} Health Care Spending - amount of resources dedicated for health care, maternal care, child development, and education
Systematic provision of a society for the optimal well-being of its members, percentage of national health expenditure devoted to local health services, percentage of population with adequate access to health care as a function of income level, fair and impartial access to physical and physiological health care regardless of economic or social status, percentage of population covered by primary health care as a function of income level.

C_{12} Population and Public Infrastructure - The total human population, including men, women and children.

Adequate physical and social infrastructure for the efficient functioning of society, Money spends for public infrastructure needing major repairs. The idea of sustainable development stems from the environmental and conservation movement of the 1970's and was largely centered on the environment. Currently, sustainability includes other questions of how resources are used, where they are taken from, who gets to use the resources, who gets to profit from the resources, and, finally, who decides all of the above.These are issues that now have legal, social, and ethical considerations. There are no easy solutions to these problems, but in the end, someone is going to be making decisions which affect everyone on Earth. As the Sustainable Development at large involves so much of indicators, uncertainties and unpredictability's, we felt it deem fit to use fuzzy theory in general and fuzzy cognitive maps in particular. For, FCMs are the best-suited tools when the data is an unsupervised one. Further the FCMs are so powerful that they can give the hidden pattern of the problem.

III. USE OF FCM TO ANALYZE SUSTAINABLE DEVELOPMENT USING THE INDICATORS

Here we analyze the impact of sustainable development on the environment with respect to the following indicators.
The following 12 Sustainable Development Indicators were taken as the attributes for analysis as nodes of the FCM.

C_1 Acts of Terrorism and Crime - Number of terrorist acts and Overall crime rate within India
C_2 Agriculture Land Conversion - Prime agricultural land area converted to urban use per year
C_3 Capital Assets -Total value, in rupees, of India tangible reproducible capital, excluding all public infrastructure, as defined in the National Asset Accounts
C_4 Consumption Expenditures Per Capita - Total rupee value of goods and services
purchased by consumers per year as defined in the National Income Accounts.
C_5 Discrimination Cases - Number of caste discrimination cases brought before courts
C_6 Ecosystem Diversity -: Area of threatened ecosystems organized by type
C_7 Energy Consumption by Use - Total Energy consumed organized by use (construction, transportation, production, heating, etc.)
C_8 Environmental Technology Sales - Total amount of money spent of environmental technology
C_9 Faith in Justice - Number of people who believe the court system is fair
C_{10}Groundwater Contamination and Groundwater Draw down- Area of land with
contaminated ground water and Change in depth of water table over time
C_{11} Health Care Spending - amount of resources dedicated for health care, maternal
care, child development, and education
C_{12} Population and Public Infrastructure - The total human population, including men, women and children.

We proceed on to give the opinion of three different experts: One is the senior-most welfare economist . Our second expert is one of the public in the village where we have studied the problem. The third expert is development policy officer.

The related connection matrix M_1 given by the first expert is a 12×12 matrix.

$$M_1 = \begin{bmatrix} 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 & 0 & 1 \\ -1 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 1 \\ -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 \\ -1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & 1 & -1 & 1 & -1 & 0 & 0 & 1 & 0 & -1 & -1 & 1 \\ -1 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & -1 & 0 & 1 \\ -1 & 1 & -1 & 1 & -1 & 1 & 0 & 0 & 0 & -1 & 0 & 1 \\ 1 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & -1 & 0 & 1 \\ -1 & 1 & 1 & 1 & -1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ -1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \end{bmatrix}$$

Let us start with the node C_3 in the ON state i.e. C_3 - Capital Assets -Total value, in rupees, of India tangible reproducible capital, excluding all public infrastructure, as defined in the National Asset Accounts the impact on Sustainable Development.

Let the input state vector X_1 = (0 0 1 0 0 0 0 0 0 0 0 0). The effect of X_1 on the dynamical system M_1 is given by

X_1M_1 =(-1 1 0 0 0 0 0 0 0 -1 0 1)
↪ (0 1 1 0 0 0 0 0 0 0 0 1) =X_2
X_2M_1 = (-3 1 1 2 1 1 0 1 0 -2 0 2)
↪(0 1 1 1 1 1 0 1 0 0 0 1)= X_3
X_3M_1 = (-5 5 0 5 -1 3 2 4 1 -1 0 6)
↪(0 1 1 1 0 1 1 1 1 0 0 1)=X_4.
X_4M_1 = (-6 5 -2 6 2 2 1 3 0 -6 -1 7)
↪ (0 1 1 1 1 1 1 1 0 0 0 1)=X_5
X_5M_1 = (-6 5 0 6 -2 3 2 4 1 -4 0 7)
↪ (0 1 1 1 0 1 1 1 1 0 0 1) =X_6=X_4

(Where ↪ denotes the thresholding and updating of the resultant state vector) The hidden pattern is the fixed point given by (0 1 1 1 0 1 1 1 1 0 0 1) which implies that except the attributes C1, C5, C10, C11, all the other attributes come to ON state i.e., except Acts of Terrorism and Crime, Discrimination cases, Groundwater contamination and groundwater drawdown, health care spending.

The related connection matrix M_2 given by the second expert is a 12×12 matrix.

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$$M_2 = \begin{bmatrix} 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & -1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & -1 & 0 & 1 \\ 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & -1 & 0 & 1 \\ 1 & 1 & -1 & 1 & 0 & 1 & 1 & 0 & 0 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 & 1 & 0 & 0 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 \\ -1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & -1 & 0 & 1 \\ 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ -1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \end{bmatrix}$$

Once again we start with the same state vector i.e. the node C_3 is in the ON state that is X_1 = (0 0 1 0 0 0 0 0 0 0 0 0). When C_3 is in the ON state all other nodes are in the OFF state. The effect of X_1 on the dynamical system M_2 is

X_1M_2 = (1 1 0 1 1 1 1 1 1 1 0 1)
↪(1 1 1 1 1 1 1 1 1 1 0 1) = X_2
X_2M_2 = (6 9 -1 8 9 4 4 5 5 -7 1 10)
↪(1 1 1 1 1 1 1 1 1 0 1 1) =X_3
X_3M_2 =(4 8 0 8 9 3 3 4 4 -7 0 10)
↪(1 1 1 1 1 1 1 1 1 0 0 1)=X_4.
X_4M_2 =(5 8 -1 7 8 3 3 4 4 -7 0 9)
↪(1 1 1 1 1 1 1 1 1 0 0 1) =X_5 = X_4

(where ↪ denotes the thresholding and updating of the vector) The hidden pattern is the fixed point given by (1 1 1 1 1 1 1 1 1 0 0 1) which implies that except the attributes C10 and C11, all the other attributes come to ON state except Groundwater contamination and groundwater drawdown, Healthcare spending being highlighted in a strong manner. The third related connection matrix M_3 given by the third expert, an Policy Development officer and who concentrates on his activities to bring in awareness about the current situation and brings awareness to the farmers, concerned authorities and the people at large.

(where ↪ denotes the thresholding and updating of the resultant state vector) The hidden pattern is the fixed point given by (0 1 1 1 0 1 1 1 0 0 0 1) which implies that except C_1 , C_5, C9, C_{10} and C_{11}, all other are coming to the ON state. That is except Act of terrorism and Crime, Discrimination cases, Faith in justice, Groundwater contamination and groundwater drawdown, Healthcare spending.

A.Use of Combined FCM to Analyze Sustainable Development

Let $M = M_1 + M_2 + M_3$ denote the combined connection matrix of the three experts.
We take the initial vector in which once again C_3 is kept in the ON state i.e. Capital Assets -Total value, in rupees, of India tangible reproducible capital, excluding all public infrastructure, as defined in the National Asset

Accounts alone is in the ON state and all other nodes are in the OFF state. Let X = (0 0 1 0 0 0 0 0 0 0 0 0) be the initial state vector. The effect of X on the dynamical system M is given by

XM = (-1 3 0 1 1 1 1 1 1 –1 0 1)
↪(0 1 1 1 1 1 1 1 1 0 0 1) = X_1
X_1 M = (-5 19 -1 20 1 10 6 11 5 -16 -1 -22)

$$M = \begin{bmatrix} 0 & 3 & 0 & 3 & 1 & 2 & 1 & 2 & 3 & -1 & 0 & 3 \\ -1 & 0 & 0 & 3 & 1 & 2 & 0 & 2 & 0 & -1 & 0 & 3 \\ -1 & 3 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & 0 & 1 \\ -1 & 3 & 0 & 0 & 1 & 0 & 2 & 3 & 1 & -1 & 0 & 3 \\ 3 & 3 & 1 & 3 & 0 & 3 & 3 & 2 & 2 & 1 & 2 & 3 \\ -1 & 3 & -1 & 3 & -1 & 1 & 0 & 3 & 1 & -3 & -3 & 3 \\ -1 & 1 & 0 & 2 & -1 & 0 & 0 & 0 & 0 & -2 & 0 & 3 \\ -1 & 3 & -2 & 2 & -2 & 2 & 0 & 0 & 0 & -3 & 0 & 3 \\ 1 & 3 & -2 & 3 & -1 & 1 & 0 & 0 & 0 & -3 & 0 & 3 \\ -1 & 3 & 2 & 3 & -1 & 3 & 3 & 3 & 3 & 1 & 3 & 3 \\ -3 & 0 & 3 & 3 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 3 \\ -3 & 0 & 3 & 3 & 3 & 0 & 0 & 0 & 0 & -3 & 0 & 0 \end{bmatrix}$$

$$M_3 = \begin{bmatrix} 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 & 0 & 1 \\ -1 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 1 \\ -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 \\ -1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & 1 & -1 & 1 & -1 & 0 & 0 & 1 & 0 & -1 & -1 & 1 \\ -1 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & -1 & 0 & 1 \\ -1 & 1 & -1 & 1 & -1 & 1 & 0 & 0 & 0 & -1 & 0 & 1 \\ 1 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 & -1 & 0 & 1 \\ -1 & 1 & 1 & 1 & -1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ -1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \end{bmatrix}$$

Once again we start with the same initial vector with the node C_3 in the ON state, that is X_1 = (0 0 1 0 0 0 0 0 0 0 0 0) be the state vector. The effect of
X_1 on the dynamical system M_3 is given by

X_1M_3 = (-1 1 0 0 0 0 0 0 0 -1 0 1)
↪(0 1 1 0 0 0 0 0 0 0 0 1)=X_2
X_2M_3 = (-3 1 1 2 1 1 0 1 0 -2 0 2)
↪(0 1 1 1 1 1 0 1 0 0 0 1) = X_3
X_3M_3 = (-5 5 0 5 -1 3 2 4 2 -3 0 6)
↪ (0 1 1 1 0 1 1 1 1 0 0 1)=X_4
X_4M_3 = (-6 5 -2 6 -3 2 1 3 0 -6 -1 7)
↪ (0 1 1 1 0 1 1 1 0 0 0 1) =X_5
X_5M_3 = (-7 4 -1 5 -2 2 1 3 0 -5 -1 6)
↪(0 1 1 1 0 1 1 1 0 0 0 1) = X_6 = X_5

↪ (0 1 1 1 1 1 1 1 1 0 0 1) =X_2 = X_1

The hidden pattern is fixed point given by (0 1 1 1 1 1 1 1 1 0 0 1) which implies that, except the attributes C1, C10, C11, all the other attributes come to ON state Thus we get the attributes Act of terrorism and Crime, Groundwater contamination and groundwater drawdown, Healthcare spending being highlighted in a strong manner even by the combined FCM.

IV. CONCLUSION

In this paper we have analyzed using FCMs, CFCMs to find the effect of Sustainable Indicators on the Sustainable Development. We see that Capital Assets -Total value, in rupees, of India tangible reproducible capital is in on the state all indicators become on which is proved to be the hidden pattern of the dynamical system which invariably is a fixed point in which all states become on. Hence A Sustainable Development perspective tends to highlight the fact that many current policies often do not pay enough attention to long term issues, or the inter-linkages between different policy areas (such as between energy and environment). Achieving Sustainable Development therefore means improving the quality of policy making. Sustainable Development is therefore

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closely linked to Governance, Better Regulation and Impact Assessment. Indicators to measure progress are also vital.

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