ASSESSMENT OF CRITERIA-RICH RANKINGS FOR DECISION MAKERS

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FOR DECISION MAKERS

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ABSTRACT

ASSESSMENT OF CRITERIA-RICH RANKINGS FOR DECISION MAKERS

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Environmental policymaking is a difficult issue for governments. It is desirable to have the decisions based on the results of quantitative and analytical studies. On the other hand, by their very nature, many such decisions have political aspects, whose subtleties are difficult to be captured by quantitative approaches alone. It is left to the political establishments to decide how best to allocate the efforts to improve environmental conditions. In this respect, evaluating the countries by generating environmental indices and the subsequent ranking of the countries with respect to those indices is a common practice. Perhaps the best known environmental sustainability index, the Environmental Performance Index-2008 (EPI-2008), is a composite index that comprises 6 core policy categories and 25 indicators.

While recognizing the qualitative aspects of such decision making, in order to support and guide the policymaking process, we develop analytical tools to assist the process. We carefully delineate our models to be limited only to the provable quantitative properties of the available objective data. However, such data are processed into more meaningful statements concerning the available options. Specifically, using EPI-2008, meaningful mathematical models that shed further light onto the country sustainability measures are developed.

Keywords: Sustainability, Decision Making, Ranking, Environmental Policy Making, Mathematical Models

ÖZ

ZENGİN KRİTERLİ SIRALAMALARIN KARAR VERİCİLER İÇİN DEĞERLENDİRİLMESİ

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Devletler için çevre politikaları belirlemek zor bir iştir. Verilen kararların nicel ve analitik çalışmalara dayandırılması beklenmektedir. Öte yandan, birçok karar doğası gereği, nicel yaklaşımlarla anlaşılması zor olan politik cihetlere sahiptir. Çevresel şartların iyileştirilmesi konusundaki eforun dağılımı politik kuruluşlara bırakılır. Bu açıdan, çevresel ölçekler oluşturarak ülkelerin değerlendirilmesi ve ardından ülkelerin bu ölçeklere göre sıralanması yaygın bir uygulamadır. Belki en yaygın olarak tanınan çevresel sürdürülebilirlik ölçeği, Çevresel Performans Ölçeği-2008 (EPI-2008), Yale ve Columbia üniversitelerinin ortak çalışması sonucunda ortaya çıkan, 6 adet ana politika kategorisi ve 25 ölçekten oluşan kompozit bir ölçektir.

Bu çalışmada, karar verme sürecine destek vermek ve yol göstermek amacıyla analitik araçlar geliştirilmiştir. Modeller, eldeki verinin güvenilir nicel özelliklerine bağlı kalınarak dikkatlice şekillendirildi ve böylelikle eldeki veri işlenerek daha anlamlı ifadelere dönüştürüldü. Bu şekilde, EPI-2008 kullanılarak ülke sürdürülebilirliğine ışık tutan anlamlı matematiksel modeller geliştirilmiştir.

Anahtar kelimeler: Sürdürülebilirlik, Karar Verme, Sıralama, Çevresel Politika Oluşturma, Matematiksel Modeller

To My Family…

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CHAPTER 1

INTRODUCTION

As with any phenomenon, if one wants to improve, one must first measure. Moreover, if one wants to make improvements in some desirable, say cost-effective, manner, the need for quantification becomes a prerequisite.

Concerns of sustainability involve rather complex systems. There are considerations of the environment, society, and economics. Although a simple measure of "sustainability" is difficult to fathom, there are indexes and rankings which compare various countries in this respect. Our study uses the well known Environmental Performance Index (EPI) ranking. As with others, EPI identifies a set of criteria and assigns a score to each country for each criteria. The scores are given weights to obtain a final aggregate country score. Countries are then ranked according to their scores.

Mathematically speaking, there is information lost as one moves from a vector of country scores (each element of the vector displaying the score received for each of the criteria) to a scalar aggregate score. Clearly, the way the weights are assigned to the various criteria has an effect on the final scores and the final rankings.

Thus, simply observing the final ranking does injustice to the wealth of information, from which the final scalar aggregate scores were extracted. The situation is most inadequate for the decision maker who wants to improve the sustainability score of his country. We are cognizant of the fact that such decision making will inevitably include subjective aspects. After all, societal and cultural considerations must be present in such decision making.

Our study meticulously delineates objective facts from others. We develop analytical methods to extract meaningful properties of the data. In this sense, our models allow the decision maker to view the data from various angles, and add his subjective judgment to arrive at the chosen course of action.

As an example, consider a set of criteria and two countries with their scores in each of the criteria. For a given set of weights, one could easily deduce which country is "more sustainable." However, there is more that can be extracted from the given data. For instance, is it possible to modify the weights given to each of the criteria to make Country A appear to be "more sustainable" than Country B? Clearly, the answer to this query depends on the scores received by each country. If Country A has scored higher in each one of the criteria, then there is no way for Country B to achieve a higher aggregate score. On the other hand, if Country A has scored higher on some of the criteria, and Country B on others, then it is possible to adjust the weights to make either country appear to be "more sustainable."

The methods developed in the following chapters rely on optimization techniques. Most queries give rise to mixed integer programming models. The cases where "best approaches" to the improvement of rankings in the presence of limited resources are also discussed.

The rest of the thesis is organized as follows: In Chapter 2, we review sustainability and its measures. Chapter 3 overviews the Environmental Performance Index (EPI) and Chapter 4 presents the basic analytical methods. In Chapter 5 we present our mathematical models together with their solutions. In Chapter 6 we conclude our study.

CHAPTER 2

SUSTAINABILITY AND SUSTAINABILITY INDICATORS

The brief definition of sustainability is "to use resources in such a way as to meet needs now and provide for needs in the future." In an ecological context, sustainability is defined in the Brundtland report "Our Common Future" of the United Nations World Commission on Environment and Development as "the ability of an ecosystem to maintain ecological processes, functions, biodiversity and productivity into the future." (Wikipedia, 2008).

Sustainability Indicators

We overview two well-known sustainability indicators.

Ecological Footprint and Biocapacity

Gorobets (2008) defines ecological footprint as ``The area of biologically productive land and water needed to provide ecological resources and services to sustainably support human population and absorb its wastes given the prevailing technology.`` The Ecological Footprint Index of a country is deduced by converting the total resource consumption of a specific country into its counterpart of hectares of biologically productive land and then dividing it by population of the country. The Ecological Footprint Index is often expressed in units of hectares per capita. Biocapacity refers to the capacity of a given biologically productive area to generate an on-going supply of renewable resources and to absorb its wastes. Non-sustainability occurs if the area's ecological footprint exceeds its biocapacity (Wikipedia, 2008).

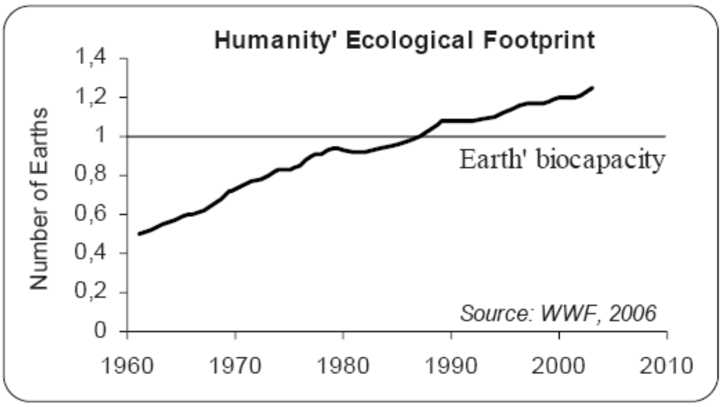

Figure 2.1 Ecological Footprint From 1961 to 2003 (Gorobets.2008)

Reviewing the changes in global ecological footprint reveals that the humans have been living beyond their means since 1987. According to this measure, human beings are now using the equivalent of 1.25 times the resources of the planet (Assadourian, 2008).

Environmental Sustainability Index (ESI):

ESI is a composite index, measuring how sustainable a society is. ESI tracks 76 variables in 21 indicators, which are grouped in 5 components. These components are:

- Environmental Systems
- Reducing Environmental Stresses
- Reducing Human Vulnerability
- Social and Institutional Capacity
- Global Stewardship (ESI.2005.pp. 11)

A brief description of ESI components, indicators and variables and information about the 2005 ESI Score of Turkey is placed in Appendix A.

CHAPTER 3

ENVIRONMENTAL PERFORMANCE INDEX (EPI)

Environmental policymaking is a difficult issue for the governments. The decisions should depend on the results of quantitative and analytical studies. In order to support and guide the policymaking process, it is desirable to have several analytical tools available to the decision makers. Evaluating and comparing the countries by generating environmental indexes and subsequently ranking the countries with respect to those indexes is a common practice. One of those indexes is the EPI (Environmental Performance Index-2008) generated with the collaboration of the Center for Environmental Law & Policy of Yale University and the Center for International Earth Science Information Network (CIESIN) of Columbia University.

EPI provides a useful tool for steering environmental investments, refining policy choices, optimizing the impact of limited financial resources, and understanding the determinants of policy results. Typically, several factors are distilled into a composite country index. Perhaps the best known environmental sustainability index, EPI-2008 is a composite index that comprises 6 core policy categories and 25 indicators. The policy categories are:

- Environmental Health
- Air Pollution (Effects on Ecosystem)
- Water
- Biodiversity & Habitat
- Productive Natural Resources
- Climate Change

The data for 25 indicators are collected from the studies and databases of the following international and national organizations:

- World Health Organization (WHO)
- United Nations Environment Program (UNEP)
- United Nations Children's Fund (UNICEF)
- The World Bank
- International Monetary Fund (IMF)
- OECD Producer Support Estimates database
- United Nations Food and Agriculture Organization's (FAO)
- International Energy Agency (IEA)
- The National Center for Atmospheric Research (NCAR)
- Joint Research Centre's Global Burned Areas
- Center for International Earth Science Information Network (CIESIN)
- University of New Hampshire Water Systems Analysis Group
- Sea Around Us Project and the Convention on Biological Diversity
- World Wildlife Fund (WWF),
- World Conservation Monitoring Centre (UNEP-WCMC)
- World Conservation Union – World Commission on Protected Areas (IUCN-WCPA)
- Conservation Strategies Division, The Nature Conservancy
- United Nations Environment Program GAMS/Water Programme
- European Environment Agency Waterbase Rivers & Lakes

Information about EPI 2008 score of Turkey is available in Appendix B.

The 25 EPI indicators are listed in the Table 3.1

Table 3.1 EPI Indicators (Source: EPI 2008)

Indicator	**Indicator Description**
ACSAT_pt	Adequate sanitation
WATSUP_pt	Drinking water
DALY_pt	Environmental burden of disease
INDOOR_pt	Indoor air pollution
PM10_pt	Urban particulates
OZONE_H_pt	Health ozone
SO2_pt	Sulfur dioxide emissions
OZONE_E_pt	Ecosystem ozone
WATQI_pt	Water quality
WATSTR_pt	Water stress
FORGRO_pt	Growing stock change
CRI_pt	Conservation risk index
EFFCON_pt	Effective conservation
AZE_pt	Critical habitat protection
MPAEEZ_pt	Marine Protected Areas
EEZTD_pt	Trawling intensity
MTI_pt	Marine Trophic Index
IRRSTR_pt	Irrigation Stress
AGINT_pt	Intensive cropland
AGSUB_pt	Agricultural Subsidies
BURNED_pt	Burned Land Area
PEST_pt	Pesticide Regulation
GHGCAP_pt	Emissions per capita
CO2IND_pt	Industrial carbon intensity
CO2KWH_pt	Emissions per electricity generation

The hierarchical relations between the 6 EPI policy categories and 25 EPI indicators are sketched in the Figure 3.1.

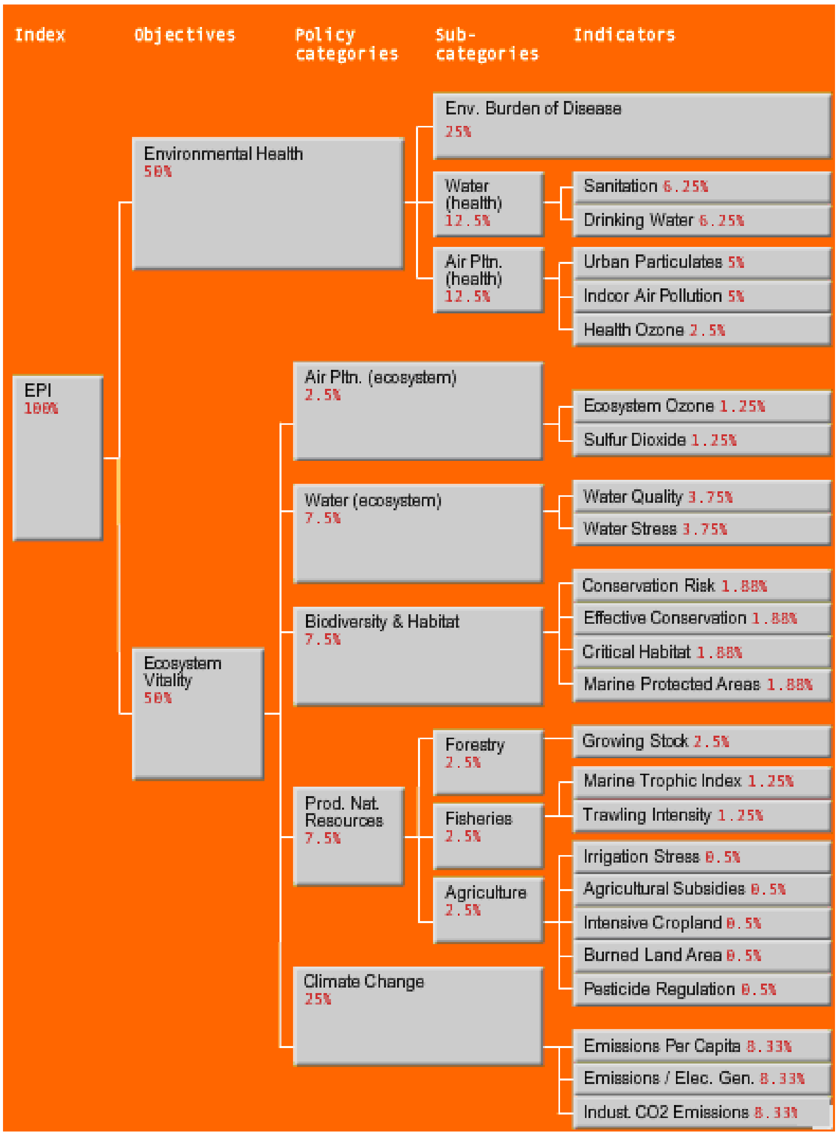

Figure 3.1 Hierarchy and weighting of EPI indicators (Source: EPI 2008)

3.1 Environmental Health

The environmental health has the following subcategories. We now explain each subcategory in detail.

Environmental Burden of Disease (DALY_pt)

The Disability Adjusted Life Year (DALY) is a health gap measure that extends the concept of potential years of life lost due to premature death (PYLL) to include equivalent years of ‘healthy’ life lost by virtue of being in states of poor health or

disability (Murray et al. 2002). The DALY is the sum of the number of life years lost due to premature mortality caused by environmentally influenced disease and the years of healthy life lost due to disability caused by such disease.

Unit: Years of life lost per 1.000 population
Target : 0

Water Pollution (Effects on Human Health)

There are sound reasons to include both a Drinking Water and an Adequate Sanitation indicator in the Environmental Health measurement. The WHO identifies diarrhea as the disease most attributable to the quality of the local environment. It is estimated that environmental factors account for 94% of the global disease burden of diarrhea (WHO 2006). Measures of Drinking Water and Adequate Sanitation correlate strongly with diarrheal diseases. One of the main sources of diarrheal disease is contamination by fecal-oral pathogens, which is largely caused by inadequate drinking water and the inadequate sanitation infrastructure. The WHO has estimated that 88% of diarrhea cases result from the combination of unsafe drinking water, inadequate sanitation, and improper hygiene (WHO 2006).

Adequate Sanitation (ACSAT_pt)

The 2008 EPI uses an Adequate Sanitation indicator from WHO Country Profiles on the Environmental Burden of Disease. This WHO dataset calculates the percentage of a country’s population with access to an improved source of sanitation. This metric is used to estimate the environmental risk individuals face from exposure to poor sanitation. The assumption is that those with access to adequate sanitation facilities are less likely to come into contact with harm causing bacteria and viruses than those without such facilities.

Target: 100 % coverage

Drinking Water (WATSUP_pt)

The data set records the percentage of a country's population with access to an improved drinking water source. Although this metric does not perfectly capture the quality of water that individuals receive, it is the best available for measurement of exposure to environmental risk.

The target for the Drinking Water indicator is set at 100% (derived from UN Millennium Development Goal (MDG) 7, Target 10, and Indicator 31). This target reflects the belief that every person ought to have access to safe drinking water.

Target: 100 %

Air Pollution (Effects on Human Health)

The WHO estimates that, of all diseases, lower respiratory tract infections are the second most attributable to environmental factors (WHO 2006). Such infections are frequently caused by air pollution. The 2008 EPI seeks to capture the health risks posed by air pollution with three indicators: Indoor Air Pollution, Urban Particulates, and Local Ozone

Urban Particulates (PM10_pt)

The 2008 EPI uses the Urban Particulates indicator to capture these risks. Urban Particulates measures the concentration of small particles, between 2.5 and 10 micrometers (PM 2.5 to PM10) in diameter, suspended in air. The target for Urban

Particulates is set at an annual mean of 20 micrograms per cubic meter, which is derived from an air quality guideline set by the WHO (WHO 2005)

Unit: micro-grams per cubic meter
Target: 20 $\mu g/m^3$

Indoor Air Pollution (INDOOR_pt)

Burning solid fuel indoors releases harmful chemicals and particles that present an acute health risk. These chemicals and particles can cause numerous respiratory problems including acute lower respiratory tract infections. One recent study has concluded that 4.6% of all deaths worldwide are attributable to acute lower respiratory tract infections caused by indoor fuel use (WHO 2006).

The Indoor Air indicator is a measure of the percentage of a country's inhabitants using solid fuels indoors. The 2008 EPI uses data from WHO Country Profiles on the Environmental Burden of Disease, which capture exposure to indoor smoke risks. The data are adjusted to account for reported ventilation in each measured home to best estimate actual exposure (WHO methodology annex). The target for Indoor Air is set by expert judgment at zero.

Unit: Percentage of population using solid fuels
Target: 0 %

Health Ozone (OZONE_H_pt)

Ground-level ozone causes significant health impacts, including respiratory distress and increased mortality. The target level for this category in the 2008 EPI is an ozone exposure limit of 85 parts per billion (ppb). This is based on the established United States EPA standard (EPA 2007).

Unit: Exceedance person ppb per capita

Target: 0 ppb

3.2 Ecosystem Vitality

The EPI builds on measures relevant to the goals of reducing environmental stresses on human health, which is called Environmental Health objective. It also includes measures relevant to the goal of reducing the loss or degradation of ecosystems and natural resources called Ecosystem Vitality objective. The core policy categories for Ecosystem Vitality include Climate Change, Air Effects on Ecosystems, Water Effects on Ecosystems, Biodiversity and Habitat, and Productive Natural Resources.

Regional Ozone with Effects on Ecosystem (OZONE_E_pt)

Ozone accumulates about 15 to 50 kilometers above the surface of the Earth in a protective layer that reflects ultraviolet radiation. Ozone can corrosively damage plant surfaces and irritate animal tissues. Plants can also directly absorb ozone through their pores, which can severely inhibit their functioning and growth. Thus ozone has the potential to degrade overall ecosystem health and reduce crop productivity.

The parameter that is chosen for assessing the critical level of ozone exposure for vegetation is the Accumulated Ozone Threshold of 40 parts per billion (ppb). The target comes from the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops and stipulates that long-term ozone exposure should not exceed 3000 ppb-hours over the three-month summer period.

Units: Exceedance square-kilometer-hours per square kilometer

Target: 0 exceedance above 3000 ppb.h

Sulfur Dioxide Emissions (SO2_pt)

Sulfur dioxide is the major cause of acid rain, a well-publicized phenomenon that degrades trees, crops, water, soil, and buildings and monuments.

The sulfur dioxide indicator included in the 2008 EPI is based on estimates of emissions compiled by the Netherlands Environment Assessment Agency's Emission Database for Global Atmospheric Research (EDGAR). This database contains global emissions inventories of greenhouse gases from anthropogenic sources measured in the year 2000.

The given uniform emissions target can be too stringent for some localities while too lax for others. After consulting with experts on this issue, the target for the 2008 EPI is simply and uniformly 0 sulfur dioxide emissions. But it is impossible to be 0.

Units: Metric Tons
Target: 0 tons SO2 / populated land

Water Quality (WATQI_pt)

Many different physical, chemical, and biological parameters can be used to measure water quality. The water quality parameters chosen for the 2008 EPI, which are from the Water Quality Index (WATQI)

Five water quality parameters were chosen for the 2008 EPI: Dissolved Oxygen, pH, Conductivity, Total nitrogen, and Total phosphorus. Dissolved oxygen is the measure of free (i.e., not chemically combined) oxygen dissolved in water. The measure of the acidity or alkalinity of a water, pH, is an important parameter of water quality in inland waters. Conductivity is a measure of the ability of water to carry an electric current, which is dependent on the presence of ions. Increases in conductivity can lead to ecosystem changes that reduce biodiversity and alter community composition. The Water Quality indicator is a proximity-to-target composite of water quality,

adjusted for monitoring stations' density in each country, with the maximum score of 100.
Target: 100 Score

Water Stress (WATSTR_pt)

Water Stress is calculated as the percentage of a country's territory affected by over-subscription of water resources. The 2008 EPI utilizes data from the University of New Hampshire's Water Systems Analysis Group. The target for each country is to have no area of their territory affected by over-subscription. Water use is represented by local demands summed by domestic, industrial, and agricultural water withdrawals and then divided by available water supply to yield an index of local relative water use.

Units: Percent of national territory with water withdrawals exceeding 40% of available supply
Target: 0% territory under water stress

Biodiversity & Habitat

Biodiversity – plants, animals, microorganisms and the ecological processes that interconnect them – forms the planet's natural productivity. Protecting biodiversity ensures that wide range of "ecosystem services" like flood control and soil renewal, the production of commodities such as food and new medicines, and finally, spiritual and aesthetic fulfillment, will remain available for current and future generations.

Conservation Risk Index (CRI_pt)

The Conservation Risk Index (CRI) compares the area of each land biome in a country that has been converted to other land uses (e.g., for example conversion from forests to cropland) to the area of each biome that is under protection. This indicator represents a more comprehensive measure of whether countries protect their natural environments on the same spatial scale as the habitats being converted.

The CRI provides a ratio of converted lands to protected lands for each terrestrial (land) biome within a country. It is also based on two 1-kilometer global spatial datasets: the World Database on Protected Areas 2007 (WDPA 2007), which reports the location and distribution of protected areas, and the Global Land Cover 2000 (GLC 2000), which compares the areas of natural habitat converted to human uses to those not converted. Percent area converted is calculated by comparing land area classified as "cultivated," "managed," or "under artificial surfaces" versus unconverted land area as reported in the GLC 2000. The target is the global average of 1:2 (protected: converted) per terrestrial biome within a country.

Target: 0.5 ratio

Effective Protected Area Conservation (EFFCON_pt)

Establishing protected areas has been a leading and widespread terrestrial ecosystem conservation strategy for decades. As a result, data on the location and extent of protected areas is some of the most consistent data across countries. Signatories to the Convention on Biological Diversity (CBD) agreed to a policy target of protecting 10% of terrestrial, freshwater, and marine habitats within each country.

The effective protected area conservation index assigns points for each terrestrial biome, or type of habitat, protected within a country. This index was calculated by spatially overlaying two 1-kilometer grid spatial datasets: the World Database on Protected Areas (2007) and the Wildlife Conservation Society Human Influence Index (also called the Human Footprint). By combining these global datasets, the index measures how much habitat within protected areas is actually intact or relatively intact.

Target: 10 % ratio

Critical Habitat Protection (AZE_pt)

Indices that investigate species conservation by country can be difficult to develop. This is partly due to the fact that for countries with larger natural endowments, there are greater conservation burdens both in terms of absolute numbers and percentages of total species to protect. This means that even if a country takes extensive measures to protect a species in its own territory, it might still rank poorly on an index that looks at the percentage of globally endangered species. It catalogs whether countries provide critical habitat protection for species identified as endangered by the Alliance for Zero Extinction (AZE). The Alliance for Zero Extinction is a joint initiative of 52 biodiversity conservation organizations. The target is the protection of 100% of sites, with the justification that there are a finite number of sites and the species in question are highly endangered. Countries with no AZE sites on their territories have total scores averaged around this indicator.

Target: 100 %

Marine Protected Areas (MPAEEZ_pt)

Marine Protected Areas (MPAs) are the aquatic equivalent of terrestrial reserves. They are legally set aside for protection from human disturbances, such as fishing, industrial exploitation, and recreational activities (depending on the type of MPA). The Marine Protected Areas (MPA) indicator measures the fraction of a country's exclusive economic zone (EEZ) it protects. Protected area criteria were taken from MPA Global, a database developed in conjunction with the "Sea Around Us Project". The indicator was calculated by comparing the area of MPA (km2) to the country's total area of EEZ, as reported in the Global Maritime Boundaries database. The target is the protection of 10% of EEZ waters, in accordance with the goals set by the Convention on Biological Diversity. Land-locked countries with no EEZ territory have scores averaged around this indicator (see methodology for a full discussion of weighting).

Target: 10 % area

Productive Natural Resources

This policy category is divided into three subcategories: Forestry, Agriculture and Fisheries. Each of these three sectors faces a set of unique management challenges, often stemming from excessive resource demand, waste, or damaging methods of exploitation.

Forestry

Forests cover almost 30% of the Earth's terrestrial surface (FAO 2006). They harbor much of the world's biodiversity, provide invaluable ecosystem services such as the production of atmospheric oxygen, and are a major productive resource for commodities ranging from traditional medicines and food to wood and paper.

Change in the Volume of Growing Stock (FORGRO_pt)

Growing stock is defined as the standing volume of the trees in a forest above a certain minimum size. Higher growing stock signifies more standing biomass, which often translates to better forest conditions. But it is important to note that standing tree volume alone is not a sufficient metric for detailed analysis of forest health.

For the purposes of target selection in this metric, it is assumed that an increase in growing stock indicates improving forest conditions while a decrease in growing stock indicates degrading forest conditions. The 2008 EPI target is zero change in growing stock as calculated by FAO in the years 2000-2005. This is consistent with the logic that cutting forests faster than their rate of regrowth is an unsustainable and environmentally harmful policy.

Unit: cubic meters/hectare
Target: no decrease

Marine Trophic Index (MTI_pt)

The marine trophic level ranges from 1 in plants to 4 or 5 in larger predators. It expresses the relative position of fish and other animals in the hierarchical food chain that nourishes them. They provide food for small fish which, have a trophic level of about 3, and the small fish are eaten by slightly larger fish that have a trophic level of 4, which, in turn, are what large predators such as sharks and marine mammal and humans typically eat. If the average level at which a country's fisheries is catching fish declines over time, it means that the overall the trophic structure of the marine ecosystem is becoming depleted of larger fish higher up the food chain, and is resorting to smaller fish.

This indicator measures the slope of the trend line in the Marine Trophic Index (MTI) from 1950-2004. If the slope is 0 or is positive, the fishery is either stable or improving. If the slope is negative (below 0), it means the fishery is declining, and that smaller and smaller fish are being caught.

Unit: Slope of Trend Line
Target: No Decline

Trawling Intensity (EEZTD_pt)

Bottom trawling is a common method for catching bottom-dwelling species such as shrimp and flounder. This involves dragging heavy gear across the sea floor, which destroys habitats and captures many non-target species such as other fish and invertebrate species, marine mammals, seabirds, and turtles. Bottom trawled fisheries have the highest discards rates of all fisheries.

The 2008 EPI Trawling Intensity indicator consists of the percentage of the shelf area in each country's EEZ that is fished using trawling. There are no direct data available for the area trawled on a country-by-country basis. However, fish landings data are acceptable as a proxy for each country's fishing fleet. The target level selected for this indicator is 0% area trawled, reflecting the opinion that any use of this fishing method is ecologically undesirable.

Target: 0% area

Agriculture

With a rapidly expanding global population, agriculture needs to meet the dual challenge of increasing food production while sustaining environmental goods and services. Approximately 70% of the world's terrestrial surface is currently at least partly devoted to agricultural uses (LEAD 2006). According to the Pilot Analysis of Global Ecosystems, cropdominated landscapes or mosaics comprise about 30 percent of the earth's total land area, and only limited areas remain that are entirely unaffected by agriculture.

Irrigation Stress (IRRSTR_pt)

Agriculture is by far the world's largest use of "blue water" (freshwater from streams, lakes, groundwater aquifers, etc.) accounting for 70% of freshwater extraction globally and as much as 80-90% in some developing countries. While irrigation is a necessary part of food production in many regions of the world, it is essential to manage irrigation practices in a way that leaves enough water both for human use and ecosystem services.

The Irrigation Stress indicator (Water Stress in Irrigated Areas) is based on a measurement of water stress developed by the University of New Hampshire Water Systems Analysis Group. Water stress is present when rates of freshwater withdrawal exceed rates of replenishment though rainfall and natural flow. While countries can accommodate some rate of oversubscription in an isolated region via inter-basin transfer, ultimately overdrawing a water resource diminishes surface water, which degrades habitat for plants and animals. The target for this indicator is for each country to experience no extreme water stress in irrigated areas.

Target: 0 %

Agricultural Subsidies (AGSUB_pt)

The Agricultural Subsidies indicator measures subsidies as a proportion of agricultural value. For countries where this data is available, Nominal Rate of Assistance (NRA) is used, defined as the price of a product in the domestic market, less its price at a country's border, expressed as a percentage of the border price, and adjusted for transport costs and quality differences (WDR 2008). Direct comparisons remain possible between the two different measures of subsidy levels due to the proximity-to-target mechanism employed. The calculations have not been adjusted to exclude "green box" subsidies that have positive environmental impacts. There are few countries where such subsidies are a very significant share of the total. The EPI target is set at no agricultural subsidies.

Unit: Proximity-to-Target, with 100 being the target, and 0 being the worst performer
Target: 0 NRA; for imputed values, 0% of agricultural GDP

Cropland Intensity (AGINT_pt)

Ecologists agree that if more than 30% of the area of a given landscape is under intensive use for agricultural production, then major ecosystem functions will likely be compromised, and if this level reaches 60%, then special attention is needed to conserve ecosystem functions.

The Cropland Intensity indicator measures the proportion of cropland in agricultural landscapes, and sets a target of 40% uncultivated land in areas of crop production. Since uncultivated land includes land left fallow, grazing land, and settlements, this target is quite conservative. Large blocks of uncultivated land or wilderness near agricultural areas will not impact a country's performance in this indicator. Only countries that have significant agricultural area covered horizon-to-horizon with cultivated crop fields score poorly for the indicator.

Target: 0 %

Burned Land Area (BURNED_pt)

Burning of cropland, grassland and forest has long been recognized as a significant source of carbon emissions and airborne particulates, especially in developing countries. Thus from an atmospheric perspective burning is has an unambiguously negative effect.

The Burned Land Area indicator (Proportion of Total Land Area Burned) is built on data taken from the Joint Research Centre's Global Burned Areas 2000-2007 estimates, and calculated for this indicator by CIESIN Global Rural-Urban Mapping Project (GRUMP) land area and country grids. A unit of land 'burned' if at any time during the year fire was observed. Accordingly the target is set as zero burned land.

Target: 0 %

Pesticide Regulation (PEST_pt)

Pesticides are a significant source of toxics in the environment, affecting both human and ecosystem health. Although newer pest control agents are often less toxic than earlier ones, pesticide-related problems remain, including mismanagement of toxic agents which remain in the environment beyond their intended usage as crop protection agents. Pesticides damage ecosystem's health by killing beneficial insects, pollinators, and fauna.

The Pesticide Regulation indicator is based on national participation in the Rotterdam Convention, which controls trade restriction and regulations for toxic chemicals, and the Stockholm convention, which bans the use of Persistent Organic Pollutants (POPs). POPs are toxic pollutants that bioaccumulate and move long distances in the environment. Accordingly the Pesticide Regulation indicator also considers national efforts to ban the 9 POPs which are relevant to agriculture: Aldrin, Chlordane, DDT, Dieldrin, Endrin, Heptachlor, Hexachlorobenzene, Mirex, and Toxaphene. The two treaties and nine pollutants create a total of 11 measures; each assigned two points, for a total possible target score of 22. Countries receive the full 22 points if they have signed both conventions and submitted a national implementation plan, as well as banned the 9 POPs. If countries have only signed the convention, but submitted no implementation plan, they receive a score of "1" for that measure, and if they are not party to the convention they receive a score of "0". A banned pesticide receives a score of "2," a restricted pesticide a score of "1," and a pesticide with no regulation receives a "0".

Unit: 22 Point Scale, with 0 representing the lowest score, and 22 the highest
Target: 22

Emissions per capita (GHGCAP_pt)

Countries with larger populations tend to emit more GHG emissions. It is not especially valuable, however, to simply measure total contribution to climate change when that contribution is largely based on population size. Thus, a more useful comparison across countries is to measure environmental performance by carbon dioxide emissions per person:

GHG Emissions, 2005 (M*etric Tons* CO_2 *Equivalent*) / *Total Population*, 2005

A country that achieves a smaller ratio for this indicator will have lower relative contributions to climate change per person. Countries in the developing world generally have the lowest per capita emissions due to small industrial sectors and lifestyles that have relatively low energy intensities. The EPI uses a target value of 50% below 1990 levels by 2050 as the basis for the per capita emissions reduction target. Since the Emissions per Capita indicator represents emissions against population, it is also necessary to set a “target” population value.

Unit: Metric Tons C02 Equivalent Per Person
Target: 2.24 Metric Tons C02 Equivalent

Industrial Carbon Intensity (CO2IND_pt)

Simply comparing total emissions per capita is not sufficient to fully measure performance. The emissions intensity of the industrial sector reflects the extent to which GHGs are being managed within a country’s industrial economy. This indicator is most commonly represented by the industrial sector carbon dioxide emissions per gross domestic product of the industrial sector:

Industrial GHG Emissions, 2005 (*Metric Tons* CO_2) / *Industrial GDP*, *PPP*, 2005 ($)

Countries that perform best on this indicator are those that have invested in low-carbon growth in their industrial sectors through energy conservation, investment in clean technologies, or other changes that result in industrial processes with lower emissions.

The target for emissions intensity of the industrial sector is 0.85 metric tons carbon dioxide equivalent per $1,000 (USD, 2005, PPP) of industrial GDP. This value is a reduction that is proportionate to the target for GHG emissions per person.

Unit: CO2 per $1000, USD 1995 PPP

Target: 0.85 tons CO2 per $ 1000

Emissions per unit Electricity Generation (CO2KWH_pt)

Since the majority of GHG emissions are generated in the energy sector, it is widely recognized that the greatest proportion of emissions reductions will have to occur within this sector. Consequently, an indicator that reflects emissions intensity of the energy sector highlights which countries have the most inefficient energy production. A useful proxy, therefore, is calculated using GHG emissions per unit of electricity and heat output.

GHG Emissions, 2005(*Metric Tons CO_2 Equivalent*) / *Electricity and Heat Output* (*kWh*)

Countries that have invested in policies promoting energy efficiency or derive energy from renewable energy sources will score higher for this indicator. In contrast, countries that meet their electricity demand entirely with fossil fuels or fuel wood will take lower scores.

The target value is chosen as zero emissions per unit of output as the theoretically ideal target for the Emissions per Electricity Generation indicator. Many climate change economists have argued that abating pollution to the point of zero emissions is not optimal due to the exponentially increasing costs of abating the last units of pollution.

Unit: gr CO2 per kWh

Target: 0

3.3 A Critique on Methodology used at EPI-2008

149 countries have been evaluated and ranked based on 6 core policy categories and 25 indicators. The methodology of the calculation of Environmental Performance Index (EPI) scores of countries can be summarized as follows:

I. **Data Collection** for each country and indicator
II. **Target Value Selection** for each indicator
III. **Normalizing** the data with respect to target value of each indicator by using the proximity-to-target methodology
IV. **Determination of weights** (level of importance) for the indicators by employing expert judgment
V. **Calculating the overall score** of each country by calculating weighted averages of normalized data
VI. **Ranking and evaluating** countries according to the overall EPI Score and its indicators

The result of the 6th step, which is the ranking of the countries, is strongly dependent on the calculations done in the previous steps. The data collected for the EPI Score calculation are scientific and reliable. However, the determination of weights for indicators (in 4th step) is based on expert judgments. Expert judgments are used in most of MCDM methods such as Analytic Hierarchy Process (AHP), Multi-Attribute Utility Theory (MAUT) and etc.

In the EPI-2008 study, the Environmental Performances of 149 different countries have been evaluated. Those countries are ranked according to the overall EPI score. The ranking is based on the collected data and weights of the 25 indicators used in EPI study. The effect of the weights of the indicators is significant in the ranking of the countries in terms of presenting the performance of the countries with respect to the 25 indicators. The current weight set for the indicators and consequently the current ranking are not unique. If we do not use current given weight set for the indicators, there will be $149! = 3.2 \times 10^{260}$ possible rankings. The current expert-judgment-based weight set gives us only one of these possible rankings.

Intuitively, the data collected seem to have more embedded information than that may be perceived by the final result of a single list showing the ranking of the countries. There may be more insight that could be obtained, other than determining which country is the first, the second, etc.

The current approach, methodology, and practice seem to ignore this rich content. Revealing the rich content may improve decision making. Our position as engineers makes us more inclined towards absolute, tangible and objective information, rather than subjective judgments. As a principle, our work only deals with factual results, directly obtained from the data using mathematical procedures.

For instance, with the given data, considering the entire range of possible weights that could be prescribed by the experts, we may wonder about, what the achievable best rank for any county is. This question and some other are actually a mathematical query.

CHAPTER 4

ANALYTICAL METHODS FOR DECISION MAKING

Our study investigates the appropriate ways in which the sustainability index or score of a society or country could be increased subject to limited resources, such as funds or time. Equivalently, we regard the ranking of a country in a set of countries. Thus, we take the view of maximizing the score or improving the rank of a given country. However, since the score is typically a composite or aggregate measure, the task of improving a given score typically has several facets, which need to be considered by a decision maker. Our intent is to supply the decision maker with analytical and objective tools and measures to support the decision making process. Before we present our models, in this chapter, we review the various pertinent optimization techniques.

4.1 Method Used for Decision Making

Widely used methods for decision making are Single Criteria Decision Making, Multi Attribute Decision Making, and Multi Objective Optimization

4.1.1 Single Criteria Decision Making

It is very important to make a distinction between the cases where we have a single criterion for decision making, or multiple criteria. A decision problem may have a single criterion or a single aggregate measure such as cost, distance, time. Then the decision can be made implicitly by determining the alternative with the best value of the single criterion or aggregate measure. Then the problem can be viewed as a classic form of an optimization problem: the objective function is the single criterion; the constraints are the requirements and restrictions placed on the alternatives. Depending on the form and functional description of the optimization problem, different optimization techniques can be used for the solution, such as linear programming, nonlinear programming, discrete optimization (Nemhauser et al. ,1989).

4.1.2 Multi Attribute Decision Making

The multi-attribute decision making problems involve a set of criteria and alternatives. For instance, there may be m criteria (C_1,C_2,…,C_m) and n alternatives (A_1,A_2,…,A_n). Let a_{ij} describe the performance of alternative A_j with respect to criterion C_i. The matrix of a_{ij} is named as "decision table." In the decision table, each row belongs to a criterion and each column designates the performance of an alternative. The weights (w_1,w_2,…,w_m) seen in the decision table denote the relative importance of each criterion. Finally, (x_1, x_2,…,x_n) values designate the final ranking of the alternatives.

		x_1			x_n
		A_1	.	.	**A_n**
w_1	**C_1**	a_{11}	.	.	a_{m1}
.	.	.	.	.	.
.	.	.	.	.	.
w_m	**C_m**	a_{m1}	.	.	a_{mn}

Figure 4.1 Decision Table

In multi-attribute decision making techniques, alternatives are completely or partially ranked and the selection of alternatives is done based on this ranking (Fülöp, 2002).

4.1.3 Multi Objective Optimization

The majority of the studies consider a single criterion like minimizing total cost or maximizing total profit. However in practice, there are usually many criteria that need to be considered simultaneously. In particular, the increasing effect of

globalization gives rise to safety, environmental impact and sustainability issues, hence their related performance measures, into consideration. The practical aim is to

find solutions that are not only economically profitable, but also environmentally safe, green and sustainable.

Generically, a multi-objective optimization problem can be expressed by the following mathematical model.

Where X denotes the decision variable set, Ω is the feasible region and $f_i(x)$ is the i^{th} objective function (criterion). This feasible region is composed of inequality or equality constraints.

Min or Max $F(x) = \{f_1(x), f_2(x),\ldots, f_k(x)\}$ (*i*)

s.t. $x \in \Omega$ (*ii*)

In a sustainability score case, we typically have two criteria: Rank and cost (budget used) i.e., $f_1(x)$ = rank, $f_2(x)$ = budget

Generally, multi-criteria optimization problems are handled in two ways;

i. Constrained Optimization
ii. Unconstrained Optimization

i. Constrained Optimization: The mathematical model of a constrained optimization can be written as two ways.

Min $f_i(x)$

s.t. $f_j(x) \leq k_j \quad \forall \; j \neq i$

In constrained optimization, one or more of the criteria are put into the objective function, whereas the remaining criteria act as constraints. In case of two objectives, one can define two constrained optimization problems.

Min f_1

s.t. $f_2 \leq k$

or

Min f_2

s.t. $f_1 \leq k$

ii. Unconstrained Optimization: There are two types of unconstrained optimization problems:

a. Specified Objective Function Problems
b. Unspecified Objective Function Problems

a. Specified Objective Function Problems: Generically, Specified Objective Function Problems are represented by following way:

Min $f(f_1,f_2)$

when $f(f_1,f_2) = w_1f_1 + w_2f_2$ (a linear function), i.e., we have a linear function the problem reduces to the simple weighting problem.

Simple weighting problem is a single Objective Function Problem. Hence, it is the simplest multi objective optimization method and is widely used. (Liu et al., 2003)

b. Unspecified Objective Function Problems: These problems generate all non-dominated, i.e., efficient solutions. This type of models are used to make trade-offs between different alternatives. The basic trade of question is "Is it worth to improve f_1 as is would worsen f_2?"

Efficient frontier: A set of efficient solutions is referred to as efficient frontier. It is also called as non-inferior, non-dominated or the Pareto-optimal solution of the problem. x^t is called an efficient solution, if there does not exist any $x \in \Omega$ ($x \neq x^t$), so that $F(x) \leq F(x^t)$, where f_i ($i = 1,2,\ldots,k$) are assumed to be minimized.

Consequently, the optimal solution to any non-decreasing function of f_1 and f_2 is on the efficient (non-dominated) frontier. Hence, if the objective function of the decision maker is unknown, but non-decreasing in f_1 and f_2, or, known but nonlinear in f_1 and f_2, one may generate the efficient frontier. In case the objective function is known, the decision maker may evaluate each efficient solution and select the one that best satisfies its concerns.

4.2 Queries

Let us first present a few aspects of the EPI data and define a few items.
There are 149 possible ranks any given country may receive. These will be denoted by R (where R=1,2,..,149).
There are 25 indicators whose weights will be denoted by W_i (where i=1, 2,…, 25).
Country n is the evaluated country that is chosen randomly.
The score vector for country n will be denoted by S_{in} (where i=1, 2,…, 25). Each element of the score vector is the score associated with criterion i.

We now present the queries of interest. Each query is a specific question, whose answer is obtained objectively and analytically. The query and associated findings constitute the factual base upon which the decision maker may base his decisions, often involving subjective considerations along with the facts presented by the queries.

The answers to the queries can be found by relying on either single criterion optimization or multi criterion optimization.

First Query Set: Finding Weight Set

Based on Ranking

- What is the best rank that country n could achieve?
  (Finding the best rank with no restrictions on weights)
- What is the worst rank that country n can get?
  (Finding the worst rank with no restrictions on weights)
- For which weight set, would country n receive given rank R?
  (Finding the weight vector based on the given rank)

Based on Score

- What is the best score that country n could achieve?
  (Finding the best score, with no restrictions on weights)
- What is the worst score that country n can get?
  (Finding the worst score, with no restrictions on weights)

Second Query Set: Finding Scores

- What is the best score set that country n could achieve?
  (Finding the best score set with the given weight set)
- What is the worst score set that country n can get?
  (Finding the worst score set, with the given weight set)
- What is the score set that country n can get given rank R?
  (Finding the score set, with the given weight set for the given rank)

Third Query Set: Decision on Independent Alternative Actions

- Finding Best Allocation of a Given Budget
  - Find the best allocation of a given budget to achieve the best possible score.
  - Find the best allocation of a given budget for the given target rank
- Finding the Budget Needed to Achieve a Target Score or Ranking
  - Find the budget needed to achieve the best score
  - Find the budget needed to get the worst score
  - Find the budget needed to achieve a given target rank

Forth Query Set: Decision on Dependent Alternative Actions

- Finding the Best Allocation of a Given Budget over Actions
    - Find the best allocation of the given budget over actions to achieve the best possible score
    - Find the best allocation of the given budget over actions to achieve a given ranking
- Finding the Best Rank for a Given Budget Value

The first and second query sets are solved by single criteria optimization models. On the other hand, the third and forth query sets are solved by multi criteria optimization models.

We find it useful to view the data and rankings through analyses in the **weight space**. The weight space in the EPI-2008 study is a 25-dimensional space. Each dimension corresponds to one of the indicators. Since the weights are in the interval [0, 1], the 25-dimensional cube contains all possible weights. Moreover, since we insist on the idea that the weights add up to 1, the set of possible weights is a 24-dimensional plane that sits on the diagonal of this 25-dimensional cube. Another point of view may be that we have 24 degrees of freedom, while the last weight is computed as $W_n = 1 - (W_1+W_2+\ldots+W_{n-1})$. To gain insight, let us first look at a two dimensional version of the weight space.

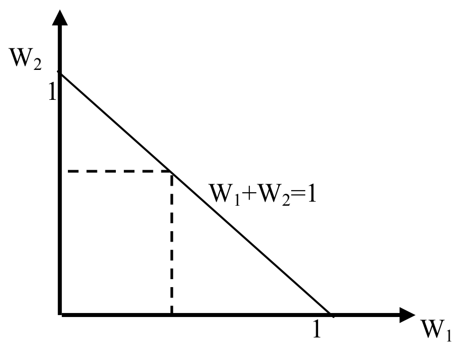

Figure 4.2 2-Dimensional Weight Space

In this graph it can be seen that the weight space is composed of w_1 and w_2. They are in the interval [0,1] and their sum is equal to 1. Then, we can examine the 3-dimensional weight space as follows:

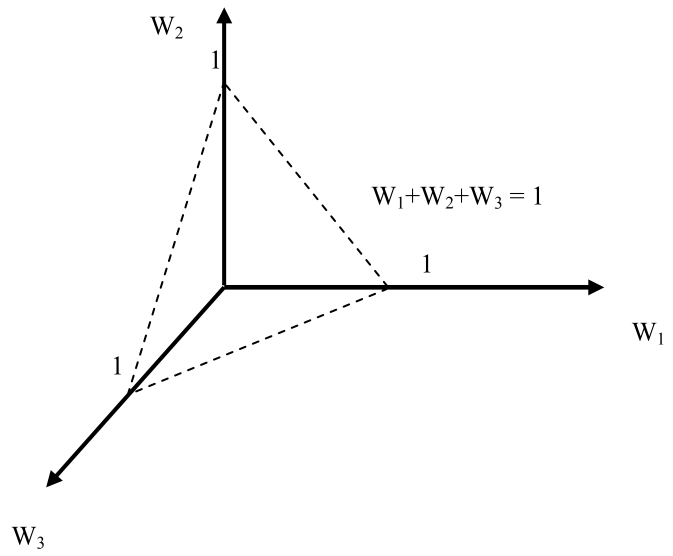

Figure 4.3 3-Dimensional Weight Space

In this graph, the 3-dimensional weight space and the plane that represents the set of possible weights sitting on the diagonal of the cube are sketched. The weight space is composed of W_1, W_2 and W_3. They are in the interval [0, 1] and their sum is equal to 1.

When we generalize the weight space as n-dimensional space, the set of possible weights is the plane which has (n-1) dimensions. In addition, the weights add up to 1.

$$W_1+W_2+\ldots+W_n = 1$$

In our case we cannot show the 25-dimensional weight space graphically. However, we can still analyze this weight space by using analytical tools.

CHAPTER 5

SCENARIOS, MATHEMATICAL MODELS AND APPLICATIONS

In this chapter, we address the queries we stated in Chapter 4. Each query refers to a different interest of a decision maker.

Let us imagine that the president of Turkey looks over the EPI rankings and notes that Turkey is on 72^{nd} place in the rankings among the 149 countries. This placement is almost in the middle of the list. In addition, most of the Middle East and Africa countries such as Egypt, Tunisia, and Israel have a better ranking on the EPI scale. Thus, although the president thinks that Turkey can do better, it is seen that there are some problems in environmental policies of the country. Afterwards, he requests forming a research team, which is composed of sustainability specialists and industrial engineers in order to analyze the EPI data and generate policies and strategies.

In this context, the research team has generated some queries we next discuss each query together with mathematical models to address the associated problems. These problems may have many optimal solutions. We aim to find one of these optimal solution. The computer codes of the models are available in Appendix C.

5.1 First Query Set: Finding Weight Set

In this query set, we aim to find weights of 25 EPI indicators. We discussed the convexity of weight set in Chapter 4. We next discuss the possible concerns of the policy maker who is interested with finding a weight set.

5.1.1 What is the best rank that country n could achieve?
(Finding the best rank, with no restrictions on weights)

The research team thought that there might be subjectivity in the evaluation procedure of the EPI ranking. They have focused on the weights of indicator used in the EPI rankings.

Weights of the indicators used in the EPI ranking report is below. Those weights are defined in the Table 5.1.

Table 5.1 List of EPI indicators and weighting

Wn	Indicator	Indicator Description	Weight
W1	ACSAT_pt	Adequate sanitation	6,25
W2	WATSUP_pt	Drinking water	6,25
W3	DALY_pt	Environmental burden of disease	25,00
W4	INDOOR_pt	Indoor air pollution	5,00
W5	PM10_pt	Urban particulates	5,00
W6	OZONE_H_pt	Health ozone	2,50
W7	SO2_pt	Sulfur dioxide emissions	1,25
W8	OZONE_E_pt	Ecosystem ozone	1,25
W9	WATQI_pt	Water quality	3,75
W10	WATSTR_pt	Water stress	3,75
W11	FORGRO_pt	Growing stock change	2,50
W12	CRI_pt	Conservation risk index	1,88
W13	EFFCON_pt	Effective conservation	1,88
W14	AZE_pt	Critical habitat protection	1,88
W15	MPAEEZ_pt	Marine Protected Areas	1,88
W16	EEZTD_pt	Trawling intensity	1,25
W17	MTI_pt	Marine Trophic Index	1,25
W18	IRRSTR_pt	Irrigation Stress	0,50
W19	AGINT_pt	Intensive cropland	0,50
W20	AGSUB_pt	Agricultural Subsidies	0,50
W21	BURNED_pt	Burned Land Area	0,50
W22	PEST_pt	Pesticide Regulation	0,50
W23	GHGCAP_pt	Emissions per capita	8,33
W24	CO2IND_pt	Industrial carbon intensity	8,33
W25	CO2KWH_pt	Emissions per electricity generation	8,33
		TOTAL	100,00

The question is “What is the best rank that the Turkey could achieve.”

Research team has defined the problem as “Finding the best rank, with no restrictions on weights.” Then the team generates a model which is represented below.

In the generated model, the weights of the indicators are somewhat restricted. The team uses the basic relations between the weights of indicators mentioned in the EPI reports as constraints of the models. EPI indicators have a hierarchic structure as sketched in Figure 3.1.

In the EPI report, the relations between the indicators are not defined for all levels. The weights of the indicators in the lowest level are equally divided without any justification. For example, the sub-criteria in the lowest level of the hierarchy from “Climate Change” criteria are “Emission Per Capita”, “Emission / Electricity Generation” and “Industrial CO_2 Emission”. These three sub-criteria are equally weighted in calculating the aggregate sustainability index.

In the model, the “equal weights” assumption is relinquished in order to see the effect of the weights on the scores and ranks. The following basic relations are used in the models in order to limit the feasible region.

Table 5.2 Weighting of EPI sub-categories

W3	=	0,250
W1+W2	=	0,125
W4+W5+W6	=	0,125
W7+W8	=	0,025
W9+W10	=	0,075
W12+W13+W14+W15	=	0,075
W11+W16+W17+W18+W19+W20+W21+W22	=	0,075
W23+W24+W25	=	0,250
TOTAL	=	1,000

Model 1.1:

The model below is a Mixed Integer Program (MIP). The assumption in the model is that all the scores of indicators for each country are constant. The only changing parameters, which are the decision variables of this model, are the weights of the indicators. Since the weight set is subject to change, so are the scores and rankings of each country.

Decision Variables:

W_i = Weight of indicator i, (i=1,2,...25)
X_j = Binary variable; 1, if country j has larger score than country n
0, o/w ; (j=1,2,.,149) ; $j \neq n$

Parameters:

S_{ij} = The score of country j for indicator i, (j=1,2,...149) ; (i=1,2,...25)
U_i = Upper bound for weight indicator i, (i=1,2,...25)
L_i = Lowest score for weight indicator i, (i=1,2,...25)
M_{j1} = A large number
M_{j2} = A large number

The objective function is to minimize Z=R, since the smaller R is the better ranking in the EPI list.

(0) MIN Z=R

Our first constraint guarantees that country n has rank R

(1) $$\sum_{j=1}^{149} X_j + 1 = R$$

The second and third constraints capture the conditional clauses. If the total score of country j, $[\sum_{i=1}^{25} W_i S_{ij}]$, is larger than the total score of country n, $[\sum_{i=1}^{25} W_i S_{in}]$ the constraint (2) and constraint (3) force binary variable X_j to 1, otherwise they force it to 0.

(2) $$\sum_{i=1}^{25} W_i S_{in} - \sum_{i=1}^{25} W_i S_{ij} \leq M_{j1} (1 - X_j) \quad \forall\ j\ (j=1,2,...149) ; j \neq n$$

(3) $\sum_{i=1}^{25} W_i S_{ij} - \sum_{i=1}^{25} W_i S_{in} \leq M_{j2} (X_j)$ $\forall$ j (j=1,2,...149) ; j ≠ n

Constraint (4) ensures that the weights of the indicators add up to 1.

(4) $\sum_{i=1}^{25} W_i = 1$

It is desirable to restrict the weight space with lower bounds and upper bounds. Constraint set (5) forces the weight of each indicator to be between a lower bound and upper bound, which are determined by expert judgment.

(5) $L_i \leq W_i \leq U_i$ $\forall$ i (i=1,2,...,25)

Moreover, in the special case of EPI, in order to narrow the feasible weight space, one can include the constraints that relate the weights of the same category. These constraints (6) to (13) are as stated below. They are determined based on expert judgment mentioned in the EPI report and stated on the Table 5.2.

(6) $W_3 = 0.25$

(7) $W_1+W_2 = 0.125$

(8) $W_4+W_5+W_6 = 0.125$

(9) $W_7+W_8 = 0.025$

(10) $W_9+W_{10} = 0.075$

(11) $W_{12}+W_{13}+W_{14}+W_{15} = 0.075$

(12) $W_{11}+W_{16}+W_{17}+W_{18}+W_{19}+W_{20}+W_{21}+W_{22} = 0.075$

(13) $W_{23}+W_{24}+W_{25} = 0.25$

In the models, we use the following big numbers sufficiently large to guarantee that the values provide upper bounds on the values that appear on the left hand side of expressions.

$M_{j1} = \max_{i=1}^{25} \{ S_{in} - S_{ij} \}$ $\forall$ j (j=1,2,...149) ; j ≠ n

$M_{j2} = \max_{i=1}^{25} \{ S_{ij} - S_{in} \}$ $\forall$ j (j=1,2,...149) ; j ≠ n

Note that $\sum_{i=1}^{25} W_i S_{in}$ - $\sum_{i=1}^{25} W_i S_{ij} = \sum_{i=1}^{25} W_i(S_{in} - S_{ij})$ and $\sum_{i=1}^{25} W_i(S_{in} - S_{ij}) \leq \text{Max}\{S_{in} - S_{ij}\}$ as W_i has an upper limit of 1 and $\sum_{i=1}^{25} W_i = 1$. Hence $M_{j1} = \text{Max}\ \{S_{in} - S_{ij}\}$ provides a valid upper bound on $\sum_{i=1}^{25} W_i\ (S_{in} - S_{ij})$ value.

Similarly, the left hand side of constraint (3), i.e., $\sum_{i=1}^{25} W_i S_{ij} - \sum_{i=1}^{25} W_i S_{in} = \sum_{i=1}^{25} W_i(S_{ij} - S_{in})$ As $W_i \leq 1$ and $\sum_{i=1}^{25} W_i = 1$, $M_{j2} = \text{Max}\ \{ S_{ij} - S_{in} \}$ provides a valid upper bound on $\sum_{i=1}^{25} W_i\ (S_{ij} - S_{in})$ value.

As mentioned, Model 1.1 is a mixed integer linear program. The only complicating component is binary decision variables, X_j s. We have 149 countries, hence 149 X_j values. Commonly available optimization software solves the integer program with 149 discrete variables quite easily. The assumption in the model is that all the scores of the indicators for each country are constant. The only decision variable is the weights of the indicators. Since the weight set is changed, the scores and rankings of each country will change.

Optimum Solution for Model 1.1

The GAMS code of the Model 1.1 is available in the Appendix C.1.

We solve Model 1.1 in GAMS solver with the existing scores of Turkey and obtain the following result.

R = 28 (rank) with the following X_j* values.

Table 5.3 X_j values for optimal solution of the Model 1.1

j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Xj*	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0

j	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Xj*	0	0	1	1	0	0	0	0	0	1	1	0	0	0	1	0	1	1	0	1

j	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Xj*	0	0	0	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1

j	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Xj*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0

j	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Xj*	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

j	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
Xj*	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

j	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140
Xj*	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

j	141	142	143	144	145	146	147	148	149
Xj*	0	0	0	0	0	0	0	0	0

Accordingly, the following 27 countries have better rank than Turkey:

Armenia	Dominican Rep.	Japan
Austria	Ecuador	Lithuania
Belarus	Estonia	Latvia
Switzerland	Finland	Malaysia
Chile	France	Norway
Colombia	United Kingdom	Portugal
Costa Rica	Croatia	Slovakia
Germany	Hungary	Slovenia
Denmark	Italy	Sweden

Table 5.4 Associated weight values for optimal solution of the Model 1.1

i	1	2	3	4	5	6	7	8	9	10	11	12	13
W_i*	0.01	0.12	0.25	0.11	0.01	0.01	0.01	0.01	0.01	0.06	0.01	0.01	0.01

i	14	15	16	17	18	19	20	21	22	23	24	25
W_i*	0.01	0.05	0.01	0.01	0.02	0.01	0.01	0.01	0.03	0.21	0.01	0.03

The total score of Turkey is $\sum_{i=1}^{25} W_i S_{in} = 83.86$

Our conclusion from the solution is that even we are free to set the weights [without violating the weights of the categories stated in the constraints (6) to (13)] the best rank Turkey can receive is 28. That is, there is no way for Turkey to be placed before the stated 27 countries while keeping the scores. For instance, complaining that the weights are not assigned fairly will not help the case of Turkey in ranking any higher than the 28th place. This means that, Turkey must improve her scores in order to achieve ranks above 28 in the EPI ranking list, even if all weights are in favor of Turkey.

5.1.2 What is the worst rank that the country n can get?
(Finding the worst rank, with no restrictions on weights)

After solving the Model 1.1, the research team thinks that the reverse of the problem should have meaningful results. This time the query is "What is the worst rank that Turkey can get?" This problem can be defined as "Finding the worst rank, with no restrictions on weights". With a little modification on the Model 1.1 the research team generates the Model 1.2 to solve the problem.

Model 1.2:

This model is similar to Model 1.1. The only difference is the objective function, which is finding the worst rank that the country n can get by maximizing the rank of country n. The resulting objective function is Max Z = R and the constraints are (1) to (13) similar with the Model 1.1.

The GAMS code of the Model 1.2 is available in the Appendix C.2.

Optimum Solution for Model 1.2

We solve the Model 1.2 solved by making use of the existing scores of Turkey we obtain the following result.

Table 5.5 X_j values for optimal solution of the Model 1.2

j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Xj*	0	1	0	1	1	1	1	1	0	1	0	0	0	1	1	1	1	1	1	1

j	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Xj*	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1

j	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Xj*	0	0	1	1	0	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0

j	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Xj*	1	1	0	1	1	0	1	1	1	1	1	1	0	1	0	0	1	0	1	0

j	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Xj*	1	1	1	1	1	1	0	1	1	0	0	0	0	0	1	0	1	1	0	0

j	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
Xj*	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	0	0

j	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140
Xj*	0	0	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	1	1	0

j	141	142	143	144	145	146	147	148	149
Xj*	1	1	0	1	1	0	1	0	1

45 countries that have lower scores than Turkey's one are following

Angola	Djibouti	Kazakhstan	Mozambique	Solomon Islands
United Arab E.	Egypt	Kyrgyzstan	Mauritania	Sierra Leone
Burundi	Eritrea	Cambodia	Malawi	Syria
Benin	Ethiopia	Kuwait	Niger	Chad
Burkina Faso	Guinea	Lebanon	Nigeria	Trin. & Tobago
Bangladesh	Guinea-Bissau	Madagascar	Pakistan	Ukraine
Cent. African Rep.	Haiti	Mali	Rwanda	Uzbekistan
China	India	Myanmar	Sudan	Yemen
Dem. Rep. Congo	Iraq	Mongolia	Senegal	Zambia

There is no chance for those countries to be ranked before Turkey for these weights.

Table 5.6 Associated weight values for optimal solution of the Model 1.2

i	1	2	3	4	5	6	7	8	9	10	11	12	13
W_i*	0.12	0.01	0.25	0.01	0.11	0.01	0.02	0.01	0.02	0.05	0.01	0.01	0.05

i	14	15	16	17	18	19	20	21	22	23	24	25
W_i*	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.24	0.01

The total score of Turkey is $\sum_{i=1}^{25} W_i S_{in} = 70{,}11$

This means, Turkey cannot get total score worse than 70,11 and rank worse than 104 among 149 countries with flexible weight set.

Combining the results of Model 1.1 and Model 1.2, we can conclude that if the weights can be changed, Turkey can be ranked in places between 28 and 104.

Moreover, these results note that every country has a range of ranking in the list if the weight set has become more flexible. The boundaries stem from the indicator scores.

We solve Models 1.1 and 1.2 for 10 different countries besides Turkey that are ranked in the first and last three places and the other four chosen from the middle of the EPI ranking list. These countries are:

Number 1: Switzerland
Number 2: Sweden
Number 3: Norway
Number 147: Sierra Leone
Number 148: Angola
Number 149: Nijer
Number 27: Albania
Number 38: Argentina
Number 39: United States
Number 72: Turkey
Number 112: United Arab Emirates

If some other countries investigated, the following results are taken from the Model 2 and Model 3. The results are summarized in the Table 5.7.

Table 5.7 EPI rank and score vs. best rank and score vs. worst rank and score

Country	EPI Rank	EPI Score	Best Rank	Best Score	Worst Rank	Worst Score	Range
Switzerland	1	95,5	1	91,1	38	85,78	37
Sweden	2	93,1	1	91,04	24	87,15	23
Norway	3	93,1	1	90,96	51	83,83	50
Albania	27	84	1	89,32	70	80,42	69
Argentina	38	81,8	3	87,14	84	76,58	81
United States	39	81	11	86,38	94	77,72	83
Turkey	72	75,9	28	83,86	104	70,11	76
United Arab E.	112	64	73	69,44	132	52,99	59
Sierra Leone	147	40	140	43,6	149	27,99	9
Nijer	149	39,1	137	52,23	149	19,94	12
Angola	148	39,5	141	37,22	149	29,65	8

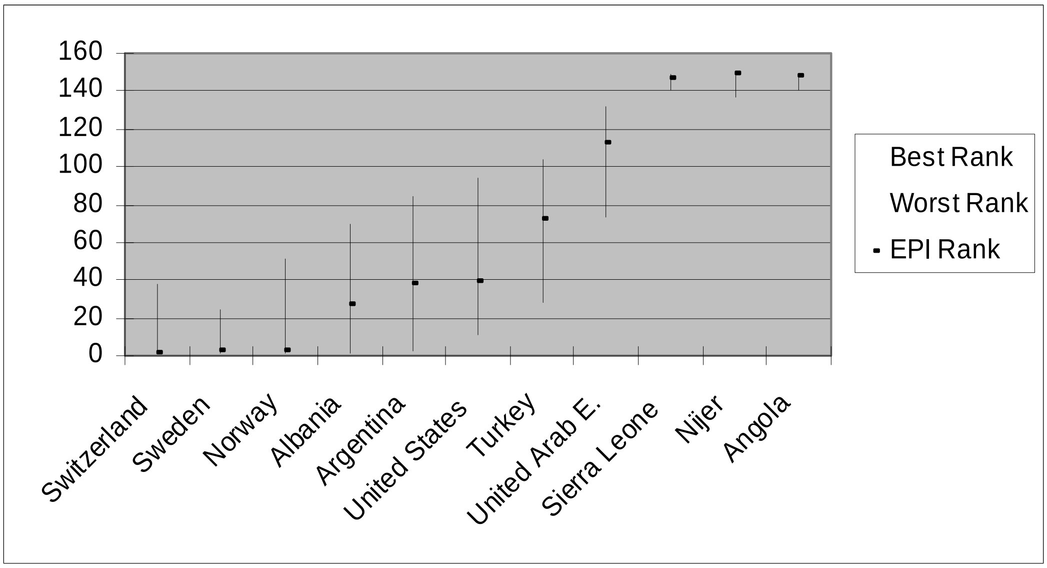

Figure 5.1 Range for ranks of countries selected

By this way clusters can be generated. Clusters designate the elasticity of the countries for the weights of the indicators. The results assigned above denote that countries having higher scores have lower elasticity for the weights. This is also true for the countries having lower scores. Rankings for the countries in the middle of the EPI Ranking list, like Turkey, Argentina, US, etc. are more responsive to changes in weights of indicators. The countries in the medium range can reach better rankings if the weights are changed. The ranges between the best possible ranking and worst possible ranking for the countries are sketched on Figure 5.1. This curve indicates the elasticity of the countries at the middle of EPI ranking list.

5.1.3 For which weight set, would country n receive given rank R? (Finding the weight vector based on the given rank)

After the research team presents the results of the first studies above the new question in the mind of the President was *"For which weight set, would Turkey receive a specific rank?" The* 40th place was the place very near to the developed countries.

The research team defines the problem as *"Finding the weight vector based on the given rank"*. Then the team generates the Model 1.3 which is represented below.

Model 1.3:

This model is quite similar to the Model 1.1 and Model 1.2. The only difference is in the Objective function. The objective function in this model should be minimizing or maximizing Z. Z is taken equal to zero in order to examine the feasibility. Our objective is just finding the most convenient feasible weight space that forces the country n achieving the rank R with the existing scores of all the countries.

The model below is Mixed Integer Program (MIP). The assumption in the model is that all scores of indicators for each country are constant. The only changing parameter, which is decision variable, is weights of the indicators. Since the weight set has changed, the scores and rankings of each country will also change.

Decision Variables:

W_i = Weight of indicator i, (i=1,2,...25)
X_j = Binary variable; 1, if country j has larger score than country n
0, o/w ; (j=1,2,.,149) ; $j \neq n$

Parameters:

S_{ij} = The score of country j for indicator i, (j=1,2,...149) ; (i=1,2,...25)
R = The given rank for the country n
U_i = Upper bound for weight indicator i, (i=1,2,...25)
L_i = Lowest score for weight indicator i, (i=1,2,...25)
M_{j1} = A big number
M_{j2} = A big number

MIN Z=0

s.t.

$$\sum_{j=1}^{149} X_j + 1 = R$$

$$\sum_{i=1}^{25} W_i S_{in} - \sum_{i=1}^{25} W_i S_{ij} \leq M_{j1}(1 - X_j) \qquad \forall\ j \ (j=1,2,...149) ; j \neq n$$

$$\sum_{i=1}^{25} W_i S_{ij} - \sum_{i=1}^{25} W_i S_{in} \leq M_{j2} (X_j) \qquad \forall\ j\ \ (j=1,2,...149)\ ;\ j \neq n$$

$$\sum_{i=1}^{25} W_i = 1$$

$$L_i \leq W_i \leq U_i \qquad \forall\ i\ \ (i=1,2,...,25)$$

$W_3 = 0{,}25$

$W_1+W_2 = 0{,}125$

$W_4+W_5+W_6 = 0{,}125$

$W_7+W_8 = 0{,}025$

$W_9+W_{10} = 0{,}075$

$W_{12}+W_{13}+W_{14}+W_{15} = 0{,}075$

$W_{11}+W_{16}+W_{17}+W_{18}+W_{19}+W_{20}+W_{21}+W_{22} = 0{,}075$

$W_{23}+W_{24}+W_{25} = 0{,}25$

X_j, binary $\qquad \forall\ j\ \ (j=1,2,...149)\ ;\ j \neq n$

$$M_{j1} = \underset{i=1}{\overset{25}{\mathrm{Max}}} \{ S_{in} - S_{ij} \} \qquad \forall\ j\ \ (j=1,2,...149)\ ;\ j \neq n$$

$$M_{j2} = \underset{i=1}{\overset{25}{\mathrm{Max}}} \{ S_{ij} - S_{in} \} \qquad \forall\ j\ \ (j=1,2,...149)\ ;\ j \neq n$$

The GAMS code of the Model 1.3 is available in the Appendix C.3.

Optimum Solution for Model 1.3

When the model runs the following weight set is obtained. If the weight set below had been used in the EPI rankings Turkey would have got the 40th place in the ranking with the existing indicator scores.

Rank 40

Score 83.56

Weights

1	0.01	10	0.07	19	0.01
2	0.12	11	0.01	20	0.03
3	0.25	12	0.01	21	0.01
4	0.04	13	0.01	22	0.01
5	0.01	14	0.04	23	0.21
6	0.08	15	0.02	24	0.01
7	0.01	16	0.01	25	0.03
8	0.02	17	0.01		
9	0.01	18	0.02		

5.1.4 What is the best score that the country n could achieve? (Finding the best score, with no restrictions on weights)

The research team may wonder about the solution with maximum total score. Maximizing score is independent from the total scores of other countries, whereas minimizing rank is dependent on the total score of other countries. This follows; minimizing rank is not equivalent to maximizing total score. In order to test the veracity of this hypothesis the Model 1.4 is formed by modifying and simplifying the Model 1.1.

Model 1.4

The new objective function is maximizing the total score of the analyzed country. In order to simplify the model we can eliminate the constraints which are related with the ranking. These are constrains (1), (2) and (3) of the Model 1.1.

Decision Variables:

W_i = Weight of indicator i, (i=1,2,...25)

Parameters:

S_{ij} = The score of country j for indicator i, (j=1,2,...149) ; (i=1,2,...25)
U_i = Upper bound for weight indicator i, (i=1,2,...25)
L_i = Lowest score for weight indicator i, (i=1,2,...25)

$$\textbf{MAX} \quad Z = \sum_{i=1}^{25} W_i S_{in}$$

s.t.

$$\sum_{i=1}^{25} W_i = 1$$

$$L_i \leq W_i \leq U_i \qquad \forall \ i \ (i=1,2,...,25)$$

$$W_3 = 0{,}25$$

$$W_1+W_2 = 0{,}125$$

$$W_4+W_5+W_6 = 0{,}125$$

$$W_7+W_8 = 0{,}025$$

$$W_9+W_{10} = 0{,}075$$

$$W_{12}+W_{13}+W_{14}+W_{15} = 0{,}075$$

$$W_{11}+W_{16}+W_{17}+W_{18}+W_{19}+W_{20}+W_{21}+W_{22} = 0{,}075$$

$$W_{23}+W_{24}+W_{25} = 0{,}25$$

The GAMS code of the Model 1.4 is available in the Appendix C.4.

The following algorithm solves this problem optimally.

Algorithm 1 – Algorithm to Solve Model 1.4

STEP 0 Set $W_i = L_i$ for all

STEP 1 Let r satisfies = Max $\{S_{in} \mid W_i < U_i\} = S_{rn}$

Set $W_r = \text{Min}\{U_r, 1-\sum W_i\}$

$W_r = W_r + \text{Min}\{U_r - W_r, 1-\sum W_i\}$

STEP 2 If $\sum W_i = 1$ then **STOP**

Go to **STEP 1**

The algorithm always gives priority to the indicator having highest score en route to maximizing total score. This indicator's weight is maximized by setting it to its upper bound. After weight corresponding to the highest score is fixed than the indicator with the next highest score is found. Its weight is maximized by considering its upper bound and weight of the indicator already fixed. The algorithm terminates when all weights add up to 1.

Optimum Solution for Model 1.4

When the model is solved by the Algothim 1, the following solution is obtained.

Rank 34

Score 86.91

Weights

1	0.01	10	0.07	19	0.01
2	0.12	11	0.04	20	0.01
3	0.25	12	0.01	21	0.01
4	0.01	13	0.01	22	0.01
5	0.01	14	0.01	23	0.24
6	0.12	15	0.06	24	0.01
7	0.01	16	0.01	25	0.01
8	0.02	17	0.01		
9	0.01	18	0.01		

Note that, in the optimum solution of Model 1.4 the maximum score for Turkey is found as 86,91 with rank 34, whereas the minimum rank was found to be 28 with score 83.86 points with the Model 1.1.

5.1.5 What is the worst score that the country n could achieve? (Finding the worst score, with no restrictions on weights)

Another concern of the research team may be the worst score that the country can take is independent of the scores of other countries, whereas worst rank is dependent on the scores of other countries. Hence minimizing total score is not equivalent to maximizing the rank. Minimizing total score problem can be formulated by the following model.

Model 1.5

Decision Variables:

W_i = Weight of indicator i, (i=1,2,...25)

Parameters:

S_{ij} = The score of country j for indicator i, (j=1,2,...149) ; (i=1,2,...25)
U_i = Upper bound for weight indicator i, (i=1,2,...25)
L_i = Lowest score for weight indicator i, (i=1,2,...25)

$$\textbf{MIN } Z = \sum_{i=1}^{25} W_i S_{in}$$

s.t.

$$\sum_{i=1}^{25} W_i = 1$$

$$L_i \leq W_i \leq U_i \qquad \forall \ i \ (i=1,2,...,25)$$

$$W_3 = 0,25$$

$$W_1+W_2 = 0,125$$

$$W_4+W_5+W_6 = 0,125$$

$$W_7+W_8 = 0,025$$

$$W_9+W_{10} = 0,075$$

$$W_{12}+W_{13}+W_{14}+W_{15} = 0,075$$

$$W_{11}+W_{16}+W_{17}+W_{18}+W_{19}+W_{20}+W_{21}+W_{22} = 0,075$$

$$W_{23}+W_{24}+W_{25} = 0,25$$

The GAMS code of the Model 1.5 is available in the Appendix C.5.

The solution of the above model is available by the following algorithm.

Algorithm 2 – Algorithm to Solve Model 1.5

STEP 0 Set $W_i = L_i$ for all

STEP 1 Let r satisfies = Min $\{S_{in} \mid W_i < U_i\} = S_{rn}$

Set $W_r = \text{Min}\{U_r, 1- \sum W_i\}$

$W_r = W_r + \text{Min}\{U_r - W_r, 1- \sum W_i\}$

STEP 2 If $\sum W_i = 1$ then **STOP**

Go to **STEP 1.**

The minimum total score algorithm uses the same idea with the maximum score algorithm. As the problem is to minimize total score, in place of maximum total score, minimum total score indicator is selected and the corresponding weight is maximized. After this weight is fixed then the indicator with the second minimum weight is selected and its weight is maximized by considering its upper bound and weight of the indicator already fixed. The algorithm terminates when all weights add up to 1.

Optimum Solution for Model 1.5

When the model is solved by the Algortihm 2, the following solution is obtained

Rank 87.00

Score 67.88

Weights

1	0.12	4	0.01	7	0.02
2	0.01	5	0.12	8	0.01
3	0.25	6	0.01	9	0.07

10	0.01	16	0.04	22	0.01
11	0.01	17	0.01	23	0.01
12	0.01	18	0.01	24	0.24
13	0.01	19	0.01	25	0.01
14	0.06	20	0.01		
15	0.01	21	0.01		

Note that the minimum total score s found as 67,88 with rank 87. On the other hand the worst rank was found as 104 with the score 70.11 by the Model 1.2. This result shows us maximizing ranking is not equivalent to minimizing total score.

5.2 Second Query Set: Finding Scores

The Model 1.1 which was generated for the Query 5.1.1 "What is the best rank that the country n could achieve?" shows that, even when the weights of the indicators are relaxed in her favor, Turkey can achieve only the 28th rank of the EPI list with the total score 83,86 based on the existing set of indicator scores. This means that, Turkey should improve the scores of indicators in order to achieve higher ranks in the EPI ranking list, even if all the weights are all in favor of Turkey. In the light of this information, the research team has focused on the scores of Turkey rather than focusing on the weights of EPI indicator. This is an issue which is perhaps more important and more controllable for any country.

5.2.1 What is the best score set that the country n could achieve? (Finding the best score set with the given weight set)

The research team aims at finding the score boundaries of Turkey. In order to find the upper score limit of Turkey they generate the Model 2.1 which is seen below.
The assumption in this model is that the scores of all countries in the list are constant, the weights of indicators are constant and the only decision variable set is the scores of Turkey from 25 indicators. The scores of each indicator for Turkey are limited

with upper bounds and lower bounds. Since the weights of indicators and scores of other countries are constant the best score means the best rank.

Model 2.1

The model has only one constraint, thus the Model 2.1 is a Knapsack Model. The significance of the model was forcing the country to adjust its scores so that it recieves the best rank.

In the model, we have a new decision variable set G_i (where i=1,2,...25), which denotes the score of country n for indicator i after the improvement. The given score vector of country n, which is S_{in} (where i=1,2,...25), is the lower bound for G_i. Additionally, an upper bound vector U_i (where i=1,2,...25) has been assigned for G_i. Moreover, in this problem we have used the original EPI weight vector stated in the Table 5.8, whereas the weight vector was a set of decision variables in the previous models.

Table 5.8 Weight set used in the Model 2.1

Wn	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13
Weight	0,0625	0,0625	0,25	0,05	0,05	0,025	0,0125	0,0125	0,0375	0,0375	0,0250	0,0188	0,0188

Wn	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25
Weight	0,0188	0,0188	0,0125	0,0125	0,005	0,005	0,005	0,005	0,005	0,0833	0,0833	0,0833

Decision Variables:

G_i = The new score of country n for indicator i,

Parameters:

W_i = Weight of indicator i, (i=1,2,...25)
U_i = Upper bound for country n for indicator i, ; (i=1,2,...25)
S_{in} = Lowest score for country n for indicator i = given scores for country n, ; (i=1,2,...25)

$$\textbf{MAX} \quad Z=\sum_{i=1}^{25} W_i G_i$$

s.t.

$$S_{in} \leq G_i \leq U_i \qquad \forall \ i \ (i=1,2,...,25)$$

The GAMS code of the Model 2.1 is available in the Appendix C.6.

Optimum Solution for Model 2.1

In the Optimum Solution the lower bound assigned as the existing scores of Turkey from 25 indicators and upper bound for each indicator assigned as 100 points.

The above model is linear program whose optimum solution is $G_i^* = U_i$. Accordingly, the total score of Turkey is 100 over 100 and the ranking is 1.

5.2.2 What is the worst score set that the country n can get? (Finding the worst score set, with the given weight set)

In order to find the lower score limit of Turkey Model 2.2 has been generated which is seen below. The assumption in this model is the scores of all countries in the list are constant, the weights of indicators are constant and the only decision variable set is the scores of Turkey from 25 indicators. The scores of each indicator for Turkey are limited with upper bounds and lower bounds. Since the weights of indicators and scores of other countries are constant, the worst score means worst rank.

Model 2.2

The model has only one constraint, thus the Model 2.2 is a Knapsack Model. The significance of the model was forcing the the country to adjust its scores so that it recieves the worst rank.

Decision Variables:

G_i = The new score of country n for indicator i,

Parameters:

W_i = Weight of indicator i, (i=1,2,...25)
U_i = Upper bound for country n for indicator i, ; (i=1,2,...25)
S_{in} = Lowest score for country n for indicator i = given scores for country n, ; (i=1,2,...25)

$$\textbf{MIN} \quad Z = \sum_{i=1}^{25} W_i G_i$$

s.t.

$$S_{in} \leq G_i \leq U_i \qquad \forall \; i \; (i=1,2,...,25)$$

The GAMS code of the Model 2.2 is available in the Appendix C.7.

Optimum Solution for Model 2.2

The lower bound assigned as the existing scores of Turkey from 25 indicators and upper bound for each indicator assigned as 100 points.

The model is linear program whose optimal solution is $G_i^* = S_{in}$, which is lower bound for G_i. Accordingly, the total score of Turkey is 75.9 and the ranking is 72.

5.2.3 What is the score set that the country n can get given rank R? (Finding the score set, with the given weight set for the given rank)

In order to exceed the score limits, Turkey should make improvement on the low scored indicators. Model 5.1 and Model 2.2 indicate the score limits and ranking limits of Turkey. In the given conditions Turkey can get scores between 75,9 and 100 and rankings between 72 and 1. This means that we can assign ranking targets between 1 and 72 for Turkey. Let us assign the same target in the optimum solution for Model 1.3, which is 40th place in the EPI ranking list. Turkey should improve its low scored indicators such as the Conservation risk index, Effective conservation, Marine Protected Areas, etc so that achieves better rankings.

This time the problem of the research team is "What is the score vector for Turkey so that it is ranked 40th?". In other words this is the problem of "Finding the score vector based on the given weight vector, for the given rank" To solve the problem research team generated the Model 2.3. In this Model weight vector is given, which is EPI weight set. The aim is finding the most reasonable vector of new scores of EPI indicators to achieve to 40th place in the ranking.

Model 2.3:

The Model 2.3 is a Mixed Integer Program (MIP) likewise Model 1.1, Mode 1.2 and Model 1.3. The significance of the model is forcing Turkey to adjust its scores so that it receives 40th place in the EPI ranking list.

Decision Variables:

G_i = The score of country n for indicator i,
X_j = Binary variable; 1, if country j has larger score than country n
0, o/w ; (j=1,2,.,149) ; j ≠ n

Parameters:

W_i = Weight of indicator i, (i=1,2,...25)
S_{ij} = The score of country j for indicator i; (j=1,2,.,149) ; j ≠ n ; (i=1,2,...25)
R = The given rank for the country n

U_i = Upper bound for country n for indicator i ; (i=1,2,...25)
S_{in} = Given scores for country n; (i=1,2,...25)
M_{j1} = A big number
M_{j2} = A big number

MIN Z=0

s.t.

$$\sum_{j=1}^{149} X_j + 1 = R$$

$$\sum_{i=1}^{25} W_i G_i - \sum_{i=1}^{25} W_i S_{ij} \leq M_{j1} (1 - X_j) \qquad \forall\ j\ \ (j=1,2,...149)\ ;\ j \neq n$$

$$\sum_{i=1}^{25} W_i S_{ij} - \sum_{i=1}^{25} W_i G_i \leq M_{j2} (X_j) \qquad \forall\ j\ \ (j=1,2,...149)\ ;\ j \neq n$$

$$S_{in} \leq G_i \leq U_i \qquad \forall\ i\ \ (i=1,2,...,25)$$

$$X_j, \text{ binary} \qquad \forall\ j\ \ (j=1,2,...149)\ ;\ j \neq n$$

$$M_{j1} = \sum_{i=1}^{25} W_i (U_i - S_{ij}) \qquad \forall\ j\ \ (j=1,2,...149)\ ;\ j \neq n$$

$$M_{j2} = \sum_{i=1}^{25} W_i (S_{ij} - L_i) \qquad \forall\ j\ \ (j=1,2,...149)\ ;\ j \neq n$$

The GAMS code of the Model 2.3 is available in the Appendix C.8.

Optimum Solution for Model 2.3

When the Model 2.3 has been run the following result gained from the compiler.

Rank 40

Score 80.53

Newscores

1	100.00	10	89.26	19	77.56
2	100.00	11	100.00	20	42.12
3	100.00	12	10.81	21	87.49
4	100.00	13	2.82	22	86.36
5	100.00	14	0.00	23	95.67
6	100.00	15	11.00	24	50.43
7	93.61	16	34.37	25	53.32
8	99.95	17	62.50		
9	53.97	18	96.82		

The model sets higher scores for the indicators has higher weight. The queries can be addressed as well;

What is the smallest total score so that the country n receives rank R at least?
What is the smallest score for indicator i so that country n receives rank R at least?

5.3 Third Query Set: Decision on Independent Alternative Actions

In the meeting government representative says that "Dear research team. Our desire is to bring Turkey to a higher place in the EPI Ranking List. We have 1.000.000 TL budget and please allocate this budget among the indicator alternatives to invest and improve them".

5.3.1 Finding Best Allocation of the Given Budget

In the following queries we have budget parameter differently than the previous queries.

5.3.1.1 Finding the Best Allocation of Budget to Achieve the Best Score

Firstly, research team defined the problem as "How can we allocate the budget among the indicators, so that Turkey achieves the possible best place in the EPI ranking list?" in other words "Finding the score vector and budget allocation with the given the weight vector for the possible best rank" The research team has made studies on this issue and come over the problem by generating the Model 3.1.1 stated below.

Model 3.1.1

This problem is a kind of trade-off problem that offers an optimal way of improvement to the policy makers among the several alternative courses of actions.

In the model, we have a new parameter set B_i (where i=1,2,...25), which denotes the budget allocated for the improvement of indicator i. Additionally, we have two new parameters. One of these is T, which is a constant number that designates the total budget of country n for the improvement and the other one is C_i (where i=1,2,...25), which denotes the cost of 1 point improvement in indicator i for country n.

This problem is a Knapsack Problem. Since the weights of indicators are given parameter the best score means the best ranking in the EPI list.

Decision Variables:

G_i = The score of country n for indicator i after the improvement, (i=1,2,...25)

Parameters:

W_i = Weight of indicator i, (i=1,2,...25)
S_{ij} = The score of country j for indicator i, (j=1,2,.,149) ; $j \neq n$; (i=1,2,...25)
T = Total budget of country n for the improvement,
B_i = Budget allocated for the improvement of indicator i, (i=1,2,...25)
C_i = Cost of 1 point improvement in indicator i for country n, (i=1,2,...25)
U_i = Upper bound for country n for indicator i, (i=1,2,...25)
S_{in} = Lowest score for country n for indicator i = given scores for country n, (i=1,2,...25)

$$\textbf{MAX} \quad Z = \sum_{i=1}^{25} W_i G_i$$

s.t.

$$S_{in} \leq G_i \leq U_i \qquad \forall\ i\ (i=1,2,...,25)$$

$$\sum_{i=1}^{25} C_i G_i - \sum_{i=1}^{25} C_i S_{in} \leq T$$

The GAMS code of the Model 3.1.1 is available in the Appendix C.9.

Optimum Solution for Model 3.1.1

In the model the following data are used as cost of 1 point improvement for each indicator

1	100000	10	14000	19	47000
2	50000	11	25000	20	10000
3	30000	12	23000	21	35000
4	40000	13	1000	22	2000
5	8000	14	25000	23	18000
6	75000	15	23000	24	76000
7	10000	16	35000	25	2500
8	25000	17	70000		
9	15000	18	45000		

And the total budget was 1.000.000 TL

When the Model 3.1.1 is run the following result obtained from the compiler.

Rank 18

Score 85.89

Budget Allocation

1	0.00	10	214760.00		
2	0.00	11	0.00	19	0.00
3	1623.00	12	0.00	20	0.00
4	0.00	13	97180.00	21	0.00
5	186160.00	14	0.00	22	0.00
6	0.00	15	0.00	23	77940.00
7	0.00	16	0.00	24	0.00
8	0.00	17	0.00	25	116700.00
9	305637.00	18	0.00		

New Scores

1	85.96	7	93.61	13	100.00
2	93.21	8	99.95	14	0.00
3	100.00	9	74.35	15	11.00
4	88.42	10	100.00	16	34.37
5	100.00	11	100.00	17	62.50
6	99.99	12	10.81	18	96.82

19	77.56	22	86.36	25	100.00
20	42.12	23	100.00		
21	87.49	24	50.43		

According to solution taken from the GAMS solver Turkey should make investment on Environmental burden of disease, Urban particulates, Water quality, Water stress, Effective conservation, Emissions per capita, Emissions per electricity generation issues in order to take the possible best rank, which is the 8^{th} rank, in the EPI ranking. Those issues are chosen by the solver since they have higher weight and lower cost of improvement with respect to other indicators as shown in the below table.

Table 5.9 EPI indicators in descending order of W_i/Cost

i	Cost	W_i	W_i/Cost
25	2500	8,33	33,32
13	1000	1,88	18,80
3	30000	25	8,33
5	8000	5	6,25
23	18000	8,33	4,63
10	14000	3,75	2,68
9	15000	3,75	2,50
22	2000	0,5	2,50
2	50000	6,25	1,25
4	40000	5	1,25
7	10000	1,25	1,25
24	76000	8,33	1,10
11	25000	2,5	1,00
12	23000	1,88	0,82
15	23000	1,88	0,82
14	25000	1,88	0,75
1	100000	6,25	0,63
8	25000	1,25	0,50
20	10000	0,5	0,50
16	35000	1,25	0,36
6	75000	2,5	0,33
17	70000	1,25	0,18
21	35000	0,5	0,14
18	45000	0,5	0,11
19	47000	0,5	0,11

Algorithm 3 – Algorithm to Solve Model 3.1.1

We also observe that the optimum solution for the above model is available through the following algorithm, hence there is no need to use MIP solver.

STEP 1. Order the indicators in their non increasing order of W_i / C_i values

Let $r = 1, C = T - \sum_{i=1}^{25} C_i S_{in}$

STEP 2. Set $G_r = \text{Min} \{ U_r, C/ C_r \}$

If $C/C_r < U_r$ or $r = n$ then **STOP** budget is used to fully

STEP 3. $C= C- C_r G_r$

$r = r +1$

Go to **STEP 2.**

The optimality of the algorithm follows the fact that one unit of capacity can be optimally used by the indicator having maximum W_i/C_i value. Hence the associated indicator should be increased till the capacity or its upper limit permits.

5.3.1.2 Finding Best Allocation of Budget for the Given Target Rank

The more complicated case is the solution of the problem "How can we allocate the budget among the indicators, so that Turkey achieves R^{th} place in the EPI ranking list?". In words "Finding the score vector and budget allocation with the given the weight vector for the given rank". The given target ranking should be between the existing ranking and possible best ranking found via Model 3.1.1.
This time the research team needs totally a new model to solve this problem. They generate the Model 3.1.2.

Model 3.1.2

The model is a Mixed Integer Program (MIP). The core sense in the first three constraints is similar with Model 1.3 and Model 2.3.

Decision Variables:

G_i = The score of country n for indicator i after the improvement, (i=1,2,...25)
B_i = Budget allocated for the improvement of indicator i, (i=1,2,...25)
X_j = Binary variable; 1, if country j has larger score than country n,
0, o/w, (j=1,2,.,149) ; j ≠ n

Parameters:

W_i = Weight of indicator i, (i=1,2,...25)
S_{ij} = The score of country j for indicator i , (j=1,2,.,149) ; j ≠ n ; (i=1,2,...25)
R = The given rank for the country n,
T = Total budget of country n for the improvement,
C_i = Cost of 1 point improvement in indicator i for country n, (i=1,2,...25)
U_i = Upper bound for country n for indicator i, (i=1,2,...25)
S_{in} = Lowest score for country n for indicator i = given scores for country n, (i=1,2,...25)
M_{j1} = A big number, (j=1,2,.,149)
M_{j2} = A big number, (j=1,2,.,149)

MIN Z=0

s.t.

$$\sum_{j=1}^{149} X_j + 1 = R$$

$$\sum_{i=1}^{25} W_i G_i - \sum_{i=1}^{25} W_i S_{ij} \leq M_{j1} (1 - X_j) \qquad \forall\ j\ (j=1,2,...149) ; j \neq n$$

$$\sum_{i=1}^{25} W_i S_{ij} - \sum_{i=1}^{25} W_i G_i \leq M_{j2} (X_j) \qquad \forall\ j\ (j=1,2,...149) ; j \neq n$$

$$S_{in} \leq G_i \leq U_i \qquad \forall\ i\ (i=1,2,...,25)$$

$$\sum_{i=1}^{25} C_i G_i - \sum_{i=1}^{25} C_i S_{in} \leq T$$

$$X_j \text{, binary} \qquad \forall\ j\ (j=1,2,...149) ; j \neq n$$

$$M_{j1} = \sum_{i=1}^{25} W_i (U_i - S_{ij}) \qquad \forall\ j\ (j=1,2,...149) ; j \neq n$$

$$M_{j2} = \sum_{i=1}^{25} W_i \ (S_{ij} - L_i) \qquad \forall \ j \ \ (j=1,2,...149) \ ; j \neq n$$

The GAMS code of the Model 3.1.2 is available in the Appendix C.10.

Optimum Solution for Model 3.1.2

In the model the following data have been used as cost of 1 point improvement for each indicator

1	100000	10	14000	19	47000
2	50000	11	25000	20	10000
3	30000	12	23000	21	35000
4	40000	13	1000	22	2000
5	8000	14	25000	23	18000
6	75000	15	23000	24	76000
7	10000	16	35000	25	2500
8	25000	17	70000		
9	15000	18	45000		

And the total budget was 1.000.000 TL and the target ranking given as 40^{th} place. When the Model 3.1.3 was run the result is:

Rank 40

Score 83.90

Budget Allocation

1	0.00	10	0.00	19	0.00
2	0.00	11	0.00	20	0.00
3	1623.00	12	0.00	21	0.00
4	0.00	13	97180.00	22	0.00
5	42030.63	14	0.00	23	0.00
6	0.00	15	742466.37	24	0.00
7	0.00	16	0.00	25	116700.00
8	0.00	17	0.00		
9	0.00	18	0.00		

New Scores

1	85.96	10	84.66	19	77.56
2	93.21	11	100.00	20	42.12
3	100.00	12	43.09	21	87.49
4	88.42	13	100.00	22	86.36
5	81.98	14	0.00	23	95.67
6	99.99	15	11.00	24	50.43
7	93.61	16	34.37	25	100.00
8	99.95	17	62.50		
9	53.97	18	96.82		

According to solution taken from the GAMS solver Turkey should make investment on "Environmental burden of disease", "Urban particulates", "Effective conservation", "Trawling intensity" and "Emissions per electricity generation" issues in order to take the 40th place in the EPI ranking. Those issues are chosen by the solver since they have higher weight and lower cost of improvement with respect to other indicators as stated in section 5.3.1.1.

5.3.2 Finding Budget Needed to Achieve a Target Score or Ranking

5.3.2.1 Finding Budget Needed to Achieve a Best Score

Research team relaxes the models from the budget constraint. The team thought that if the government has limitless budget however it has a target score for EPI ranking. The Model 3.2.1 generated in order to find the budget needed based on this suggestion.

Model 3.2.1

This model is a Knapsack problem model. Budget constraint has been removed from the Model 3.1.1

The model forces the Gi to set to Ui. Then shows the total budget needed to achieve the maximum score. This indicates the upper bound of the budget needed to make improvement in EPI ranking.

Decision Variables:

G_i = The score of country n for indicator i after the improvement, (i=1,2,...25)

Parameters:

W_i = Weight of indicator i, (i=1,2,...25)
S_{ij} = The score of country j for indicator i , (j=1,2,.,149) ; $j \neq n$; (i=1,2,...25)
C_i = Cost of 1 point improvement in indicator i for country n, (i=1,2,...25)
U_i = Upper bound for country n for indicator i, (i=1,2,...25)
S_{in} = Lowest score for country n for indicator i = given scores for country n, (i=1,2,...25)

$$\textbf{MAX} \quad Z = \sum_{i=1}^{25} C_i G_i$$

s.t.

$$S_{in} \leq G_i \leq U_i \qquad \forall \; i \; (i=1,2,...,25)$$

The GAMS code of the Model 3.2.1 is available in the Appendix C.11.

Optimum Solution for Model 3.2.1

We solve Model 3.2.1 using the cost data used in the Model 3.1.1, Model 3.1.2 and Model 3.1.3 and obtain following result. The model is linear program whose solution is already available. The optimal solution of the model assigns each score to its upper bound. We report this solution below.

Rank 1

Score 100.00

Total Budget 21186863

Budget Allocation

1	1404000.00	10	214760.00	19	1054680.00
2	339500.00	11	0.00	20	578800.00
3	1623.00	12	2051370.00	21	437850.00
4	463200.00	13	97180.00	22	27280.00
5	186160.00	14	2500000.00	23	77940.00
6	750.00	15	2047000.00	24	3767320.00
7	63900.00	16	2297050.00	25	116700.00
8	1250.00	17	2625000.00		
9	690450.00	18	143100.00		

New Scores

1	100.00	10	100.00	19	100.00
2	100.00	11	100.00	20	100.00
3	100.00	12	100.00	21	100.00
4	100.00	13	100.00	22	100.00
5	100.00	14	100.00	23	100.00
6	100.00	15	100.00	24	100.00
7	100.00	16	100.00	25	100.00
8	100.00	17	100.00		
9	100.00	18	100.00		

As stated before all the scores take the upper bound score and total cost of the maximum score is 21.186.863 TL

5.3.2.2 Finding Budget Needed to Get the Worst Score

The aim of this query is to determine the lower bound for the scores that the country can get. In the Model 3.2.2 the only difference is n the objective function. The new objective function is minimizing version of the previous one. The model forces to set G_i to the lower bound. The lower bound is existing score S_{in} , therefore there is no change in score and ranking.

5.3.2.3 Finding Budget Needed to Achieve the Given Target Rank

After the boundaries are set we can give a target ranking between the lower bound and upper bound. In our case Turkey can get the ranking between 72^{nd} place and 1^{st} place according to the budget available to invest.

This time the question against the research team is "How much money Turkey does need to achieve the given target rank?" With the aim of solving this problem research team develops a new model which is Model 3.2.3.

Model 3.2.3

Decision Variables:

G_i = The score of country n for indicator i after the improvement, (i=1,2,...25)
T = Total budget of country n for the improvement,
X_j = Binary variable; 1, if country j has larger score than country n,
0, o/w, (j=1,2,.,149) ; $j \neq n$

Parameters:

W_i = Weight of indicator i, (i=1,2,...25)
S_{ij} = The score of country j for indicator i , (j=1,2,.,149) ; $j \neq n$; (i=1,2,...25)
R = The given rank for the country n,
C_i = Cost of 1 point improvement in indicator i for country n, (i=1,2,...25)
U_i = Upper bound for country n for indicator i, (i=1,2,...25)
S_{in} = Lowest score for country n for indicator i = given scores for country n, (i=1,2,...25)
M_{j1} = A big number, (j=1,2,…149)
M_{j2} = A big number, (j=1,2,…149)

$$MIN\ T = \sum_{i=1}^{25} C_i G_i - \sum_{i=1}^{25} C_i S_{in}$$

s.t.

$$\sum_{j=1}^{149} X_j + 1 = R$$

$$\sum_{i=1}^{25} W_i G_i - \sum_{i=1}^{25} W_i S_{ij} \le M_{j1} (1 - X_j) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \ne n$$

$$\sum_{i=1}^{25} W_i S_{ij} - \sum_{i=1}^{25} W_i G_i \le M_{j2} (X_j) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \ne n$$

$$S_{in} \le G_i \le U_i \qquad \forall\ i\ (i=1,2,...,25)$$

$$X_j, \text{ binary} \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \ne n$$

$$M_{j1} = \sum_{i=1}^{25} W_i (U_i - S_{ij}) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \ne n$$

$$M_{j2} = \sum_{i=1}^{25} W_i (S_{ij} - L_i) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \ne n$$

The GAMS code of the Model 3.2.3 is available in the Appendix C.12.

Optimum Solution for Model 3.2.3

In the model the following data have been used as cost of 1 point improvement for each indicator.

1	100000	10	14000	19	47000
2	50000	11	25000	20	10000
3	30000	12	23000	21	35000
4	40000	13	1000	22	2000
5	8000	14	25000	23	18000
6	75000	15	23000	24	76000
7	10000	16	35000	25	2500
8	25000	17	70000		
9	15000	18	45000		

The target ranking has been given as 40th place of the EPI ranking.

When the Model 3.2.3 was run the result is taken.

Rank 40

Score 80.53

Total Budget 98171.77

Budget Allocation

1	0.00	10	0.00	19	0.00
2	0.00	11	0.00	20	0.00
3	1623.00	12	0.00	21	0.00
4	0.00	13	0.00	22	0.00
5	0.00	14	0.00	23	0.00
6	0.00	15	0.00	24	0.00
7	0.00	16	0.00	25	96548.77
8	0.00	17	0.00		
9	0.00	18	0.00		

New Scores

1	85.96	10	84.66	19	77.56
2	93.21	11	100.00	20	42.12
3	100.00	12	10.81	21	87.49
4	88.42	13	2.82	22	86.36
5	76.73	14	0.00	23	95.67
6	99.99	15	11.00	24	50.43
7	93.61	16	34.37	25	91.94
8	99.95	17	62.50		
9	53.97	18	96.82		

5.4 Forth Query Set: Decision on Dependent Alternative Actions

In the strategic plan of the government there is a project portfolio which consists of several projects related to environmental issues. Those projects have different impacts on environment. For instance, some cause improvement on the water related indicators; some are related on air related to indicators, etc. In this problem the main challenge is allocating the limited budget among the alternative actions. This problem is a kind of strategic planning problem that gives the optimum course of investment which improves the score of the given country to the desired level.

To be able to develop this kind of model we need a data set as stated on Table 5.10. The data set contains seven different projects from different field of actions. These are agriculture, water pollution, air pollution, forest, habitat, education, alternative energy. In addition, the impacts of the projects on the EPI indicators are stated in columns of the table. The data about cost and impact of projects stated in Table 5.10 are assigned randomly just to compile our mathematical models.

For instance, the cost of a project for making improvements on “Water Pollution” issue is 300.000 TL. This project increases the score of Turkey from the 2^{nd} indicator, which is “Drinking Water” by 5 points.

Table 5.10 Cost and impact of alternative actions on the EPI indicators

		Alternatives	1	2	3	4	5	6	7
		Cost (TL)	200K	300K	400K	500K	600K	700K	800K
		Field of Action	Agriculture	Water Pollution	Air Pollution	Forest	Habitat	Education	Alternative Energy
Indicator Description	**Weight**	**Turkey EPI**	Impact of the actions in terms of score increase						
Adequate sanitation	0,0625	85,96	1,0	5,0	0,0	0,0	0,0	3,0	2,0
Drinking water	0,0625	93,21	0,0	4,0	0,0	0,0	0,0	1,0	1,0
Environmental burden of disease	0,2500	94,59	0,0	1,0	2,0	1,0	0,0	0,0	1,0
Indoor air pollution	0,0500	88,42	0,0	0,0	4,0	2,0	0,0	2,0	3,0
Urban particulates	0,0500	76,73	0,0	0,0	5,0	2,0	0,0	2,0	4,0
Health ozone	0,0250	99,99	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Sulfur dioxide emissions	0,0125	93,61	0,0	0,0	2,0	1,0	0,0	1,0	2,0
Ecosystem ozone	0,0125	99,95	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Water quality	0,0375	53,97	3,0	8,0	0,0	0,0	0,0	4,0	2,0
Water stress	0,0375	84,66	0,0	4,0	0,0	0,0	0,0	0,0	1,0
Growing stock change	0,0250	100,00	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Conservation risk index	0,0188	10,81	0,0	1,0	2,0	0,0	6,0	3,0	1,0
Effective conservation	0,0188	2,82	0,0	2,0	0,0	2,0	9,0	5,0	1,0
Critical habitat protection	0,0188	0,00	0,0	1,0	0,0	2,0	8,0	6,0	3,0
Marine Protected Areas	0,0188	11,00	0,0	3,0	0,0	0,0	6,0	9,0	1,0
Trawling intensity	0,0125	34,37	0,0	4,0	0,0	0,0	9,0	8,0	1,0
Marine Trophic Index	0,0125	62,50	0,0	0,0	0,0	0,0	7,0	5,0	1,0
Irrigation Stress	0,0050	96,82	2,0	1,0	0,0	0,0	0,0	0,0	0,0
Intensive cropland	0,0050	77,56	5,0	0,0	0,0	0,0	0,0	5,0	1,0
Agricultural Subsidies	0,0050	42,12	6,0	0,0	0,0	0,0	0,0	3,0	1,0
Burned Land Area	0,0050	87,49	0,0	0,0	0,0	5,0	0,0	6,0	1,0
Pesticide Regulation	0,0050	86,36	3,0	0,0	0,0	0,0	0,0	6,0	0,0
Emissions per capita	0,0833	95,67	0,0	0,0	2,0	0,0	0,0	0,0	1,0
Industrial carbon intensity	0,0833	50,43	0,0	0,0	7,0	1,0	0,0	3,0	5,0
Emissions per electricity generation	0,0833	53,32	0,0	0,0	8,0	1,0	0,0	5,0	10,0

5.4.1 Finding Best Allocation of the Given Budget over Actions:

The question is how to allocate this budget among the alternative actions. This problem is a kind of trade-off problem that offers an optimal way of improvement to the policy makers among the several alternative courses of actions.

5.4.1.1 Finding Best Allocation of the Given Budget over Actions to Achieve the Possible Best Score:

There is a new decision variable vector in the model;
F_k (where k=1,2,…7) which is a binary decision variable. If F_k is equal to 1 it means the action k is chosen, if F_k is equal to 0 it means the action k is not chosen.

Also we have a new parameter matrix; Y_{ki} (where k=1,2,…7 ; i=1,…25) which denotes the impact of the action k on indicator i. This impact is in terms of point of increase in the indicator over 100 points.

The other new parameter is T which is a constant number that designates the total available budget of the country for the improvement. Also we have a new parameter vector; C_k (where k=1,2,…7) which denotes the cost of action k.

A new constraint which is "Budget Constraint" is composed of those parameters and the binary decision variable vector composed there is a new constraint. Now the model is more analogous to the real life with this budget constraint.

In order to find the upper bound of the score and the budget allocation the Model 4.2.1 has been generated by the research team.

In the model we assume that, score of the other countries are constant while the score of the country n is increasing. This problem is a typical Knapsack Problem since having only one constraint.

Model 4.1.1

Decision Variables:

G_i = The score of country n for indicator i after the improvement, (i=1,2,...25)

F_k = Binary variable; 1, if the action k is chosen,
0, o/w, (k=1,2,…7)

Parameters:

W_i = Weight of indicator i, (i=1,2,...25)

S_{ij} = The score of country j for indicator i , (j=1,2,.,149) ; j ≠ n ; (i=1,2,...25)

T = Total budget of country n for the improvement,

C_k = Cost of action k (k=1,2,…7)

S_{in} = Lowest score for country n for indicator i = given scores for country n

Y_{ki} = impact of the action k on indicator i (k=1,2,…7) ; (i=1,2,...25)

$$\textbf{MAX} \quad Z = \sum_{i=1}^{25} W_i G_i$$

s.t.

$$\sum_{k=1}^{7} C_k F_k \leq T$$

$$S_{in} + \sum_{k=1}^{7} Y_{ki} F_k = G_i \qquad \forall \; i \; (i=1,2,...25)$$

$$F_k, \text{ binary} \qquad \forall \; k \; (k=1,2,...7)$$

The GAMS code of the Model 4.1.1 is available in the Appendix C.13.

Optimum Solution for Model 4.1.1

For the very large values of T, all actions will be taken. This is a trivial solution. Let take T = 5.000.000 TL. Then the solution is taken from the compiler is:

Rank 15

Score 85.95

Budget Used 3500000

Selected Actions

1	1.00	4	1.00	6	1.00
2	1.00	5	1.00	7	1.00
3	1.00				

For Turkey, 15th rank is upper bound for ranking, 85,95 is upper bound for the score and 3.500.000 TL is upper bound for the budget will be allocated. When we use 2.500.000 TL for the Total Budget Available parameter compiler gives the following result.

Rank 19

New Score 84.48

Budget Used 2400000

Selected Actions

1	1.00	4	0.00	7	1.00
2	1.00	5	0.00		
3	1.00	6	1.00		

Because of the budget constraint compiler could not select all actions from portfolio. The most effective and less expensive actions are selected.

5.4.1.2 Finding Best Allocation of the Given Budget over Actions to Achieve the Given Ranking:

This time the problem is setting the rank of the country to a given rank in the EPI list by selecting the most convenient alternative actions. That given target rank should be between the upper bound ranking (which is equal to 72) and lower bound ranking (which is equal to 15). In order to solve the problem the Model 4.1.3 has been written.

Model 4.1.2

Because the ranking is issue in this problem the parameter R, which designates the ranking, binary decision variable X_i, very large numbers M_{j1} and M_{j2} are being used in this model. The model is a Mixed Integer Program (MIP).

Note that with the optimal budget allocation, T*, smaller ranks than R can be found. To find minimum rank for the minimum budget T* can be found using the following objective function.

$$\text{MIN } Z = \sum_{k=1}^{7} C_k F_k + \varepsilon_r \sum_{j=1}^{149} X_j$$

For a sufficiently small value of Є the above objective function will find the minimum rank solution among the minimum cost (budget) solutions.

The value of ε should be set such that $\sum_{k=1}^{7} C_k F_k + \varepsilon_r R_{MAX} < \sum_{k=1}^{7} C_k F_k + 1 + \varepsilon_r R_{MIN}$

i,e. The smallest increase in total cost value should be favored even for the largest increase in $\sum_{j=1}^{149} X_j$. This follows $\varepsilon_r [R_{MAX} - R_{MIN}] \leq 1 \Rightarrow \varepsilon_r < 1/[R_{MAX} - R_{MIN}]$, where $R_{MIN} = 1$ and $R_{MAX} = 149$.

Decision Variables:

G_i = The score of country n for indicator i after the improvement, (i=1,2,...25)
X_j = Binary variable; 1, if country j has larger score than country n,
0, o/w, (j=1,2,…149) ; j ≠ n
F_k = Binary variable; 1, if the action k is chosen,
0, o/w, (k=1,2,…7)

Parameters:

W_i = Weight of indicator i, (i=1,2,...25)
S_{ij} = The score of country j for indicator i , (j=1,2,.,149) ; j ≠ n ; (i=1,2,...25)
R = The given rank for the country n,
T = Total budget of country n for the improvement,
S_{in} = Given scores for country n, (i=1,2,...25)
Y_{ki} = impact of the action k on indicator i (k=1,2,…7) ; (i=1,2,...25)
M_{j1} = A big number, (j=1,2,…149)
M_{j2} = A big number, (j=1,2,…149)
ε_r = Very small number

$$\text{MIN } Z = \sum_{k=1}^{7} C_k F_k + \varepsilon_r \sum_{j=1}^{149} X_j$$

s.t.

$$\sum_{j=1}^{149} X_j + 1 \leq R$$

$$\sum_{i=1}^{25} W_i G_i - \sum_{i=1}^{25} W_i S_{ij} \leq M_{j1} (1 - X_j) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \neq n$$

$$\sum_{i=1}^{25} W_i S_{ij} - \sum_{i=1}^{25} W_i G_i \leq M_{j2} (X_j) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \neq n$$

$$S_{in} + \sum_{k=1}^{7} Y_{ki} F_k = G_i \qquad \forall\ i\ (i=1,2,...25)$$

$$\sum_{k=1}^{7} C_k F_k \leq T$$

X_j, binary $\qquad \forall\ j\ (j=1,2,...149)\ ;\ j \neq n$

F_k, binary $\qquad \forall\ k\ (k=1,2,...7)$

$$M_{j1} = \sum_{i=1}^{25} W_i (U_i - S_{ij}) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \neq n$$

$$M_{j2} = \sum_{i=1}^{25} W_i \ (S_{ij} - L_i) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \neq n$$

The model has 7 F_k and 149 X_j binary variables. Our software could easily handle the problems of these sizes. The GAMS code of the Model 4.1.2 is available in the Appendix C.14.

Optimum Solution for Model 4.1.2

The model has been run for the target ranking value 40th place. Also in this application we have used the data set which had been used in Optimum Solution for Model 4.1.1. In order to relax the Budget constraint we set T value to the upper bound which is 3.500.000 TL. Moreover, we set $\varepsilon_r = 1/\ [R_{MAX} - R_{MIN} + 1] = 1/\ [149-1+1] = 0,0067$. The result taken from the compiler is stated below.

Rank 40
New Score 80.57
Budget Used 1200000

Selected Actions

1	0.00	4	1.00	7	0.00
2	1.00	5	0.00		
3	1.00	6	0.00		

The result denotes that so as to Turkey achieve the 40th place in EPI ranking list should invest the second, third and forth project from the project portfolio. These are projects from the water pollution, air pollution and forestry fields. This way Turkey will achieve a score of 80.57 points. Under the assumption that the scores for all other countries are constant, Turkey can achieve the 40th rank with this score. This is the minimum cost alternative batch of projects. The total cost is 1.200.000 TL.

5.4.2 Finding the Best Rank for a Given Budget Value:

Model 4.2

Decision Variables:

G_i = The score of country n for indicator i after the improvement, (i=1,2,...25)
X_j = Binary variable; 1, if country j has larger score than country n,
0, o/w, (j=1,2,…149) ; $j \neq n$
F_k = Binary variable; 1, if the action k is chosen,
0, o/w, (k=1,2,…7)

Parameters:

W_i = Weight of indicator i, (i=1,2,...25)
S_{ij} = The score of country j for indicator i , (j=1,2,.,149) ; $j \neq n$; (i=1,2,...25)
S_{in} = Lowest score for country n for indicator i = given scores for country n, (i=1,2,...25)
Y_{ki} = impact of the action k on indicator i (k=1,2,…7) ; (i=1,2,...25)
M_{j1} = A big number, (j=1,2,…149)
M_{j2} = A big number, (j=1,2,…149)
ε_t = Very small number

$$\text{MIN } Z = \sum_{j=1}^{149} X_j + 1 + \varepsilon_t \sum_{k=1}^{7} C_k F_k$$

s.t.

$$\sum_{i=1}^{25} W_i G_i - \sum_{i=1}^{25} W_i S_{ij} \leq M_{j1} (1 - X_j) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \neq n$$

$$\sum_{i=1}^{25} W_i S_{ij} - \sum_{i=1}^{25} W_i G_i \leq M_{j2} (X_j) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \neq n$$

$$\sum_{k=1}^{7} C_k F_k \leq T$$

$$S_{in} + \sum_{k=1}^{7} Y_{ki} F_k = G_i \qquad \forall\ i\ (i=1,2,...25)$$

$$X_j, \text{ binary} \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \neq n$$

$$F_k, \text{ binary} \qquad \forall\ k\ (k=1,2,...7)$$

$$M_{j1} = \sum_{i=1}^{25} W_i (U_i - S_{ij}) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \neq n$$

$$M_{j2} = \sum_{i=1}^{25} W_i (S_{ij} - L_i) \qquad \forall\ j\ (j=1,2,...149)\ ;\ j \neq n$$

The GAMS code of the Model 4.2 is available in the Appendix C.15.

Then state that the same rank can be achieved with smaller T value. Hence a meaningful problem is to find the minimum budget usage among the solution of the same rank. We call such a solution as "efficient solution" in MCDM (Multi Criteria Decision Making) terminology. We have generated an efficient solution with respect to total budget and rank values by using the following problem:

$$\text{MIN } Z = \sum X_j + 1 + \varepsilon_t \sum C_k F_k$$

s.t. $\sum C_k F_k \leq T$

for a sufficiently small value of $\varepsilon_{t.}$ The model selects the minimum cost solution among the ones having the minimum rank value.

We set ε_t as follows:

(1) $\sum X_j + \varepsilon_t [T_{MAX}] < \sum X_j + 1 + \varepsilon_t [T_{MIN}]$

i.e., $\sum X_j$ value should not increase even for the maximum decrease $\sum C_k F_k$ value.

(2) Follows that $\varepsilon_t [T_{MAX}-T_{MIN}] < 1 \Rightarrow \varepsilon_t < 1 / [T_{MAX}-T_{MIN}]$

Where T_{MAX} value is found by solving the Model 4.1.1 and $T_{MIN} = 0$.

To find the set of all efficient solutions we use the following procedure

Algorithm 4 – Algorithm to Solve Model 4.2

STEP 0: Let $T_U = T_{MAX}$

$T_L = T_{MIN}$

$\varepsilon_t = 1 / [T_{MAX}-T_{MIN} + 1]$

$T = T_{MAX}$

STEP 1: Solve MIN $Z = \sum X_j + 1 + \varepsilon_t \sum C_k F_k$

s.t. $\sum C_k F_k \leq T$

Let the solution be (R*, T*)

If $T^* = T_L$, then **STOP**

STEP 2: Set $T = T^* - 1$

Go to **STEP 1**

Note that each execution of STEP 1 generates an efficient solution. All efficient solutions are generated when the algorithm terminates.

Optimum Solution for Model 4.2

When we apply the algorithm stated above we will be able to sketch a "pareto chart" which illustrates the relation between dedicated budget and ranking. The Model 4.2 runs 17 times by changing the value of T; which is Budget parameter. We have started running the algorithm by setting T=3.500.000, which is Upper Bound of T, T_U.

Very small number ε_t is calculated by the following formula;

$$\varepsilon_t = 1 / [T_{MAX} - T_{MIN} + 1]$$

$$\varepsilon_t = 1 / [3.500.000 - 0 + 1] = 0,00000029$$

At the end of 17 iterations we have taken the following results from the compiler. In this Optimum Solution the data set of Turkey is used and the scores of other countries are assumed constant.

Table 5.11 Outputs of 17 iterations of the Model 4.2

Iteration	T	X*	Y*	Score
1	3.500.000	15	3.500.000	85,95
2	3.499.999	16	3.300.000	85,70
3	3.299.999	17	2.900.000	85,20
4	2.899.999	18	2.800.000	84,97
5	2.799.999	18	2.700.000	84,95
6	2.699.999	19	2.400.000	84,48
7	2.399.999	21	2.200.000	84,22
8	2.199.999	33	1.900.000	82,54
9	1.899.999	35	1.500.000	82,25
10	1.499.999	36	1.400.000	81,81
11	1.399.999	39	1.200.000	80,80
12	1.199.999	41	900.000	80,09
13	899.999	42	700.000	79,84
14	699.999	50	600.000	78,64
15	599.999	52	400.000	78,39
16	399.999	60	300.000	77,41
17	299.999	66	0	75,96

The graph below shows the dependency between the dedicated Budget (Y*) and the EPI rank (X*).

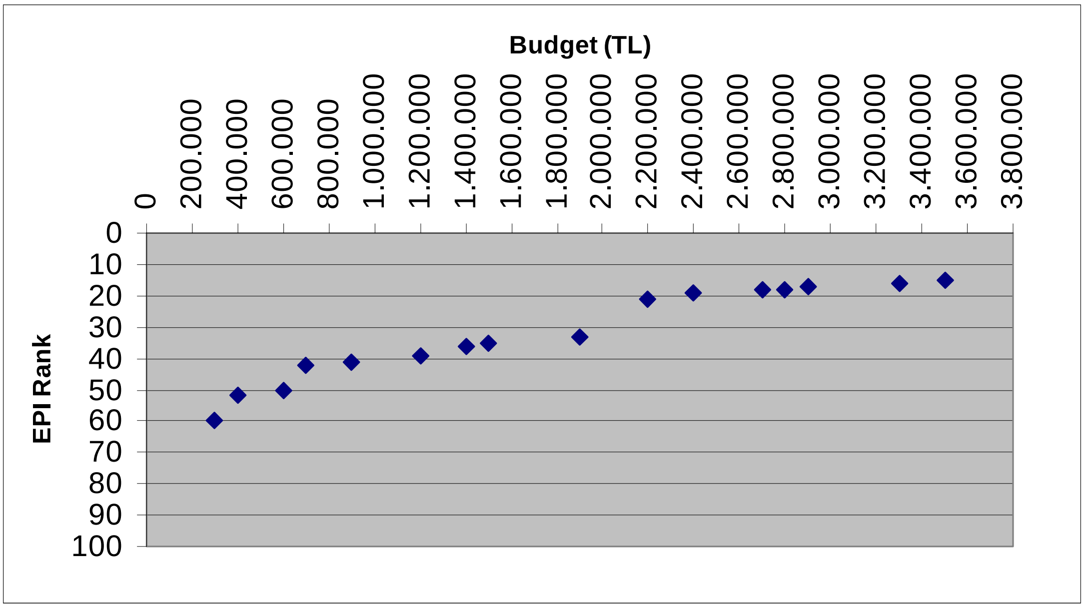

Figure 5.3 Efficient solutions (Budget vs. EPI rank) of the Model 4.2

On the Figure 5.3 there are three main jumping points. These efficient frontiers can be interpreted by the ordered pairs (Y*,X*).

Point 1 : (300.000 TL, 60th Rank)

Point 2: (400.000 TL, 52nd Rank)

Point 3: (2.200.000 TL, 21st Rank)

The first efficient frontier, Point 1, says that if Turkey invests 300.000 TL's to environmental issues, we can carry Turkey from 72nd rank to the 60th rank. The model suggests selecting the Action 2, which is the project about "Water" issue defined in Table 5.10.

The second efficient frontier, Point 2, says that if Turkey invests 400.000 TL's to environmental issues, Turkey's ranking might change from the 72nd to the 52nd . The model suggests selecting the Action 3, which is the project about "Air Pollution" issue defined in Table 5.10.

The third efficient frontier, Point 3, says that if Turkey invests 2.200.000 TL's to environmental issues, we can bring Turkey from 72^{nd} rank to the 21^{st} rank. Model suggests selecting the Action 2: Water, Action 3: Air Pollution, Action 6: Education and Action 7: Alternative Energy project defined in Table 5.10.

This information can guide the policy makers on selection of the most efficient batch of actions.

CHAPTER 6

CONCLUSIONS AND FUTURE STUDIES

We developed models that are intended to complement a decision maker who is interested in improving the "sustainability score" of his country. We limited our work to the provable facts that can be derived from a given set of data. The decision maker is expected to add more subjective aspects of the situation to arrive at a recommendation or course of action. We defined a number of queries and used optimization techniques to develop the associated models. Frequently, our models have led to mixed integer programming models that are rather easily solved with the available technology.

Although the work focuses on sustainability scores, the methodology and approach is applicable to a wider range of cases where a set of objects are evaluated according to a set of criteria. Perhaps the best known two examples are the rankings of universities and of airlines. Universities are ranked according to their faculty, facilities, sports, cost of living, etc. while airlines are ranked according to their cost, on-time departures and arrivals, lost baggage, etc. Both of these cases are similar to the EPI case, where there are many criteria and arguably subjectively assigned weights. In either case, the comparison starts with much data (all the scores for each of the criteria factors) and distills this data into a single scalar rank. While the rank is a concise measure, it hides the wealth of data, otherwise needed by a decision maker who is interested in improving his own rank. We believe that the models developed in this study will assist such a decision maker.

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APPENDIX A:

ENVIRONMENTAL SUSTAINABLITY INDEX (ESI) 2005

Table A.1 Description of 5 ESI Components (Source: ESI 2005)

Component	Logic
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.
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 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.
Social and Institutional Capacity	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.
Global Stewardship	A country is more likely to be environmentally sustainable if it cooperates with other countries to manage common environmental problems, and if it reduces negative transboundary environmental impacts on other countries to levels that cause no serious harm.

Table A.2 ESI Indicators and Variables (Source: ESI 2005)

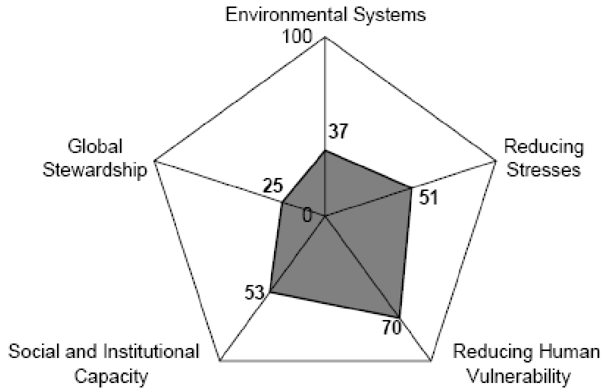
Component	Indicator Number	Indicator	Variable Number	Variable Code	Variable
Environmental Systems	1	Air Quality	1	NO2	Urban population weighted NO_2 concentration
			2	SO2	Urban population weighted SO_2 concentration
			3	TSP	Urban population weighted TSP concentration
			4	INDOOR	Indoor air pollution from solid fuel use
	2	Biodiversity	5	ECORISK	Percentage of country's territory in threatened ecoregions
			6	PRTBRD	Threatened bird species as percentage of known breeding bird species in each country
			7	PRTMAM	Threatened mammal species as percentage of known mammal species in each country
			8	PRTAMPH	Threatened amphibian species as percentage of known amphibian species in each country
			9	NBI	National Biodiversity Index
	3	Land	10	ANTH10	Percentage of total land area (including inland waters) having very low anthropogenic impact
			11	ANTH40	Percentage of total land area (including inland waters) having very high anthropogenic impact
	4	Water Quality	12	WQ_DO	Dissolved oxygen concentration
			13	WQ_EC	Electrical conductivity
			14	WQ_PH	Phosphorus concentration
			15	WQ_SS	Suspended solids
	5	Water Quantity	16	WATAVL	Freshwater availability per capita
			17	GRDAVL	Internal groundwater availability per capita
Reducing Environmental Stresses	6	Reducing Air Pollution	18	COALKM	Coal consumption per populated land area
			19	NOXKM	Anthropogenic NO_x emissions per populated land area
			20	SO2KM	Anthropogenic SO_2 emissions per populated land area
			21	VOCKM	Anthropogenic VOC emissions per populated land area
			22	CARSKM	Vehicles in use per populated land area
	7	Reducing Ecosystem Stress	23	FOREST	Annual average forest cover change rate from 1990 to 2000
			24	ACEXC	Acidification exceedance from anthropogenic sulfur deposition
	8	Reducing Population Pressure	25	GR2050	Percentage change in projected population 2004-2050
			26	TFR	Total Fertility Rate
	9	Reducing Waste & Consumption Pressures	27	EFPC	Ecological Footprint per capita
			28	RECYCLE	Waste recycling rates
			29	HAZWST	Generation of hazardous waste
	10	Reducing Water Stress	30	BODWAT	Industrial organic water pollutant (BOD) emissions per available freshwater
			31	FERTHA	Fertilizer consumption per hectare of arable land
			32	PESTHA	Pesticide consumption per hectare of arable land
			33	WATSTR	Percentage of country under severe water stress
	11	Natural Resource Management	34	OVRFSH	Productivity overfishing
			35	FORCERT	Percentage of total forest area that is certified for sustainable management
			36	WEFSUB	World Economic Forum Survey on subsidies
			37	IRRSAL	Salinized area due to irrigation as percentage of total arable land
			38	AGSUB	Agricultural subsidies

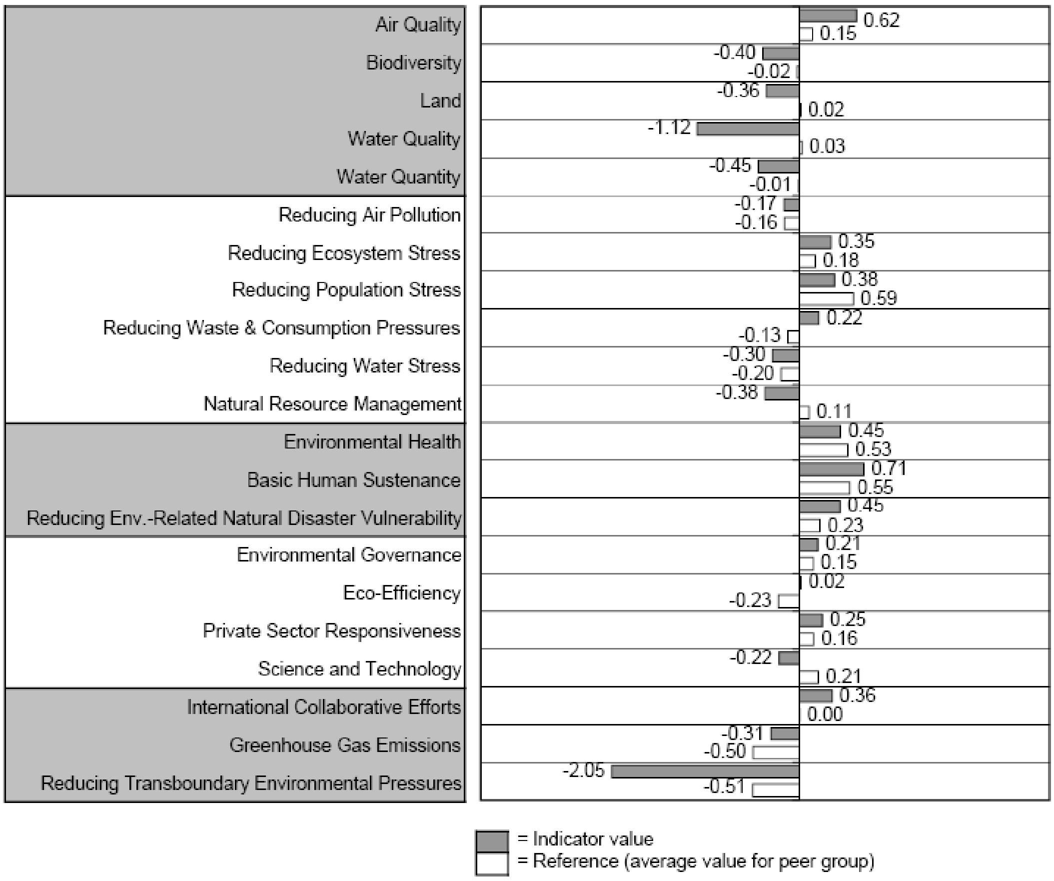
Component	Indicator Number	Indicator	Variable Number	Variable Code	Variable
Reducing Human Vulnerability	12	Environmental Health	39	DISINT	Death rate from intestinal infectious diseases
			40	DISRES	Child death rate from respiratory diseases
			41	U5MORT	Children under five mortality rate per 1,000 live births
	13	Basic Human Sustenance	42	UND_NO	Percentage of undernourished in total population
			43	WATSUP	Percentage of population with access to improved drinking water source
	14	Reducing Environment-Related Natural Disaster Vulnerability	44	DISCAS	Average number of deaths per million inhabitants from floods, tropical cyclones, and droughts
			45	DISEXP	Environmental Hazard Exposure Index
Social and Institutional Capacity	15	Environmental Governance	46	GASPR	Ratio of gasoline price to world average
			47	GRAFT	Corruption measure
			48	GOVEFF	Government effectiveness
			49	PRAREA	Percentage of total land area under protected status
			50	WEFGOV	World Economic Forum Survey on environmental governance
			51	LAW	Rule of law
			52	AGENDA21	Local Agenda 21 initiatives per million people
			53	CIVLIB	Civil and Political Liberties
			54	CSDMIS	Percentage of variables missing from the CGSDI "Rio to Joburg Dashboard"
			55	IUCN	IUCN member organizations per million population
			56	KNWLDG	Knowledge creation in environmental science, technology, and policy
			57	POLITY	Democracy measure
	16	Eco-Efficiency	58	ENEFF	Energy efficiency
			59	RENPC	Hydropower and renewable energy production as a percentage of total energy consumption
	17	Private Sector Responsiveness	60	DJSGI	Dow Jones Sustainability Group Index (DJSGI)
			61	ECOVAL	Average Innovest EcoValue rating of firms headquartered in a country
			62	ISO14	Number of ISO 14001 certified companies per billion dollars GDP (PPP)
			63	WEFPRI	World Economic Forum Survey on private sector environmental innovation
			64	RESCARE	Participation in the Responsible Care Program of the Chemical Manufacturer's Association
	18	Science and Technology	65	INNOV	Innovation Index
			66	DAI	Digital Access Index
			67	PECR	Female primary education completion rate
			68	ENROL	Gross tertiary enrollment rate
			69	RESEARCH	Number of researchers per million inhabitants
Global Stewardship	19	Participation in International Collaborative Efforts	70	EIONUM	Number of memberships in environmental intergovernmental organizations
			71	FUNDING	Contribution to international and bilateral funding of environmental projects and development aid
			72	PARTICIP	Participation in international environmental agreements
	20	Greenhouse Gas Emissions	73	CO2GDP	Carbon emissions per million US dollars GDP
			74	CO2PC	Carbon emissions per capita
	21	Reducing Transboundary Environmental Pressures	75	SO2EXP	SO_2 Exports
			76	POLEXP	Import of polluting goods and raw materials as percentage of total imports of goods and services

Table A.3 ESI Score of Turkey (Source: ESI 2005)

Turkey

ESI:	46.6
Ranking:	91
GDP/Capita:	$5,869
Peer group ESI:	52.1
Variable coverage:	71
Missing variables imputed:	2





APPENDIX B

EVNIRONMENTAL PERFRMANCE INDEX 2008 SCORE OF TURKEY

(Source: EPI 2008)

2008 Environmental Performance Index

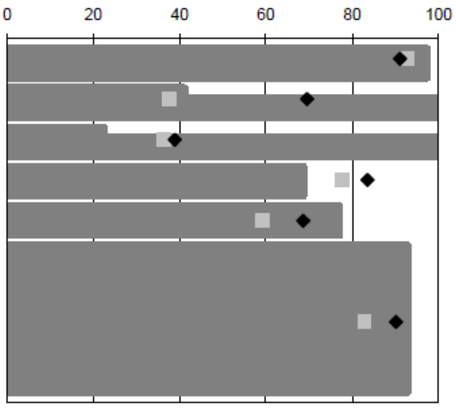
Turkey

MIDDLE EAST AND NORTH AFRICA

GDP/capita 2005 est. (PPP) $7,842
Income Decile 4 (1=high, 10=low)

2008 EPI	
Rank:	72
Score:	75.9
Income Group Avg.	79.0
Geographic Group Avg.	70.0

Policy Categories



	Country	Income Group	Geographic Group
Air Pollution (eco)	96.8	91.1	92.9
Water (eco)	69.3	69.6	37.8
Biodiv. and Habitat	5.2	38.9	36.5
Prod. Nat. Resources	75.5	83.6	77.8
Climate Change	66.5	68.6	59.2
Environmental Health	91.2	90.2	82.9

Indicator Data

		Value	Target	Proximity to Target
DALY	Environmental Burden of Disease (life years lost)	3.0	*0*	94.6
ACSAT	Adequate Sanitation (%)	88.0	*100*	86.0
WATSUP	Drinking Water (%)	96.0	*100*	93.2
PM10	Urban Particulates (μg/m^3)	47.65842	*20*	76.7
INDOOR	Indoor Air Pollution (%)	11.0	*0*	88.4
OZONE_H	Local Ozone (ppb)	0.2	*85*	100.0
OZONE_E	Regional Ozone (tons SO_2 / populated land)	189,136.0	*3,000*	100.0
SO2	Sulfur Dioxide Emissions (ppb)	2.7	*0*	93.6
WATQI	Water Quality (GEMS Water Quality Index score)	72.3	*100*	54.0
WATSTR	Water Stress (%)	13.9	*0*	87.6
CRI	Conservation Risk Index (ratio)	0.1	*0.5*	10.8
EFFCON	Effective Conservation (The Nature Conservancy, %)	0.3	*10*	2.8
AZE	Critical Habitat Protection (Alliance for Zero Extinction, %)	0.0	*100*	0.0
MPAEEZ	Marine Protected Areas (Sea Around Us Project, Fisheries Centre, UBC, %)	1.1	*10*	11.0
FORGRO	Growing Stock Change (cubic meters/hectare)	1.0	*0*	100.0
MTI	Marine Trophic Index (UBC, Sea Around Us Project)	-0.0	*0*	62.5
EEZTD	Trawling Intensity (UBC, Sea Around Us Project, %)	0.7	*0*	34.4
IRRSTR	Irrigation Stress (CIESIN, %)	2.7	*0*	96.8
AGSUB	Agricultural Subsidies (% border agricultural prices)	27.0	*0*	42.1
AGINT	Intensive Cropland (CIESIN, %)	14.2	*0*	77.6
BURNED	Burned Land Area (%)	1.7	*0*	87.5
PEST	Pesticide Regulation (points)	19.0	*22*	86.4
GHGCAP	Emissions Per Capita (Mt CO_2 eq.)	4.5	*2.24*	95.7
CO2KWH	Emissions Per Electricity Generation (g CO_2 per kWh)	433.0	*0*	53.3
CO2IND	Industrial Carbon Intensity (CO_2 per $1000, USD 1995 PPP)	4.2	*0.85*	50.4

APPENDIX C

GAMS CODES OF MODELS DEFINED IN CHAPTER 5

C.1 Model 1.1

```
$Title Model 1.1

Sets    j     countries /1*149/
        i     indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators
        1       2       3       4       5       6       7       8       9       10      11      12
13      14      15      16      17      18      19      20      21      22      23      24
25
1       19.3    20.2    0.0     0.0     40.0    0.0     98.4    0.0     29.4    93.9    95.4
99.7    95.7    0.0     14.0    74.5    100.0   97.5    100.0   100.0   0.0     9.1
65.8    95.0    63.0
2       89.5    93.2    99.5    47.4    70.1    99.1    98.5    99.8    93.0    100.0
100.0   5.5     1.6     0.0     6.0     25.1    100.0   100.0   90.2    100.0   78.9
9.1     98.8    85.0    96.3
3       97.7    100.0   98.9    94.7    11.2    100.0   70.2    100.0   0.0     54.1
100.0   100.0   2.3     0.0     1.0     0.0     100.0   51.8    100.0   100.0   96.1
13.6    38.6    32.1    9.0
4       89.5    93.2    98.0    94.7    51.3    92.4    98.8    75.7    76.4    73.4
75.9    39.8    33.9    40.0    2.0     17.5    100.0   74.6    78.4    100.0   55.7
90.9    87.1    92.7    67.0
5       80.1    86.4    98.2    72.2    59.0    100.0   98.8    100.0   31.7    24.3
70.1    37.7    10.4    0.0     100.0   0.0     0.0     97.0    94.5    100.0   79.5
100.0   98.0    78.3    85.1
6       100.0   100.0   99.6    94.7    100.0   100.0   69.9    100.0   75.3    49.6
100.0   86.1    79.0    69.4    78.0    93.5    100.0   50.7    79.6    99.9    63.3
100.0   45.4    76.2    5.9
7       100.0   100.0   99.8    94.7    87.8    99.2    94.4    99.6    59.8    100.0
100.0   80.1    63.0    0.0     100.0   0.0     0.0     100.0   63.2    22.8    96.0
100.0   81.6    82.3    75.7
8       46.2    61.0    93.0    48.4    67.0    100.0   95.4    100.0   31.7    65.4
100.0   46.2    11.9    0.0     100.0   0.0     0.0     82.9    91.1    100.0   78.4
4.5     88.7    97.1    45.6
9       25.1    64.3    26.1    0.0     84.1    99.4    99.3    99.6    25.6    100.0
0.0     84.1    40.9    0.0     100.0   0.0     0.0     100.0   92.0    100.0   87.7
100.0   94.0    100.0   50.5
10      100.0   100.0   99.6    94.7    95.4    99.7    0.6     99.8    59.6    45.0
100.0   9.6     11.5    0.0     0.0     0.0     94.9    100.0   87.1    22.8    98.6
95.5    77.7    59.7    71.1
11      21.6    44.0    40.5    0.4     80.7    73.0    99.4    83.8    20.1    100.0
17.8    98.9    98.7    0.0     0.0     83.0    100.0   100.0   87.9    100.0   57.9
95.5    93.7    96.3    23.5
12      0.0     33.8    8.1     0.0     38.0    83.3    99.8    81.6    20.1    86.6
```

64.5 46.1 83.2 0.0 100.0 0.0 0.0 96.0 99.3 100.0 79.6
63.6 97.3 99.3 36.3
13 28.7 55.9 74.8 6.4 0.0 99.6 96.1 95.2 59.3 90.3
83.1 4.4 9.5 0.0 1.0 0.0 0.0 100.0 0.0 91.7 99.3
0.0 100.0 91.3 40.0
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100.0 26.6 22.7 0.0 0.0 87.7 16.9 94.0 71.0 93.5 59.2
100.0 88.6 49.5 51.7
15 94.2 94.9 99.5 47.7 100.0 99.8 83.7 99.9 84.8 100.0
100.0 1.9 0.5 0.0 100.0 0.0 0.0 100.0 96.9 100.0 79.9
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16 81.3 100.0 99.5 80.0 100.0 100.0 97.4 100.0 31.7 98.0
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9.1 86.1 50.9 67.8
17 38.0 84.7 92.1 54.7 100.0 89.4 99.1 99.8 57.1 100.0
100.0 100.0 96.7 0.0 71.0 83.7 41.0 100.0 100.0 100.0 99.5
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18 36.8 74.5 73.0 63.8 44.3 0.0 98.8 0.0 43.7 97.7
90.2 100.0 92.4 42.9 100.0 0.0 0.0 100.0 100.0 100.0 76.3
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19 70.8 83.0 93.5 86.4 93.2 59.6 97.8 0.0 73.9 97.5
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20 32.2 91.5 88.1 31.6 59.1 0.0 98.7 82.6 29.4 66.3
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13.6 96.0 91.7 90.4

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60 18.1 21.9 63.9 0.0 81.1 100.0 99.6 100.0 59.4 98.3
86.4 5.5 0.5 18.8 0.0 72.9 0.0 100.0 55.7 100.0 98.5
0.0 100.0 85.4 66.9
61 94.2 98.3 99.6 94.7 100.0 100.0 80.8 100.0 86.3 72.9
100.0 12.1 8.9 0.0 100.0 0.0 0.0 100.0 35.7 54.8 39.4
95.5 88.7 86.1 63.5
62 47.4 61.0 91.0 24.0 30.9 99.8 97.3 95.0 73.1 99.8
0.0 73.1 99.2 19.0 10.0 40.8 100.0 100.0 82.8 42.7 99.6
86.4 90.5 72.1 16.9
63 21.6 76.2 76.6 13.9 56.6 99.8 93.9 82.0 67.7 63.0
100.0 15.0 16.6 43.8 5.0 71.9 82.6 80.3 20.1 71.9 92.9
13.6 100.0 73.8 0.0
64 100.0 100.0 99.8 94.7 100.0 100.0 97.2 100.0 65.5 100.0
100.0 24.0 2.5 0.0 0.0 39.0 98.5 100.0 95.4 22.8 99.5
95.5 74.3 97.8 37.0
65 80.1 89.8 92.8 94.7 68.2 100.0 97.6 99.9 51.3 72.0
100.0 95.1 41.4 0.0 12.0 14.7 92.8 89.4 79.1 100.0 95.4
90.9 87.3 60.7 42.4
66 75.4 67.7 69.4 94.7 0.5 100.0 97.7 100.0 21.3 71.4
100.0 2.8 0.4 0.0 0.0 0.0 0.0 70.2 65.9 100.0 98.3
0.0 97.3 0.0 24.4
67 100.0 100.0 99.6 94.7 100.0 100.0 92.0 100.0 28.5 99.0
100.0 100.0 82.9 0.0 4.0 46.5 47.1 0.0 0.0 0.0 97.6
90.9 79.5 67.4 99.9
68 100.0 100.0 99.8 94.7 85.3 100.0 50.3 100.0 67.8 16.9
100.0 72.9 64.9 100.0 13.0 83.3 0.0 77.5 53.6 0.5 96.3
4.5 85.2 79.0 17.3
69 100.0 100.0 99.8 94.7 94.0 96.9 87.7 87.8 92.8 80.5
100.0 39.3 17.6 0.0 9.0 75.1 85.1 100.0 65.3 22.8 85.7
95.5 84.9 82.3 56.3
70 76.6 88.1 96.4 52.6 81.3 100.0 73.8 100.0 59.4 100.0
100.0 66.4 28.6 40.0 5.0 92.3 0.0 0.0 83.9 100.0 0.0
90.9 94.7 92.1 23.1
71 91.8 94.9 92.8 94.7 74.5 100.0 91.2 100.0 11.9 17.2
100.0 100.0 77.3 0.0 100.0 1.3 97.4 38.0 62.6 0.5 99.8
100.0 96.2 59.1 28.8

72 100.0 100.0 99.6 94.7 90.6 98.3 83.1 84.3 78.7 93.8
100.0 93.8 25.6 27.8 2.0 75.3 81.6 100.0 97.4 0.0 96.2
100.0 83.1 74.6 53.8
73 67.3 76.2 98.2 94.7 100.0 100.0 91.5 100.0 42.8 77.8
100.0 24.6 21.3 0.0 100.0 0.0 0.0 82.9 86.2 100.0 55.9
45.5 48.4 0.0 0.0
74 33.3 33.8 58.5 34.1 84.3 100.0 99.4 100.0 56.4 84.7
90.4 100.0 82.8 100.0 12.0 91.3 76.9 95.3 97.9 92.3 81.4
18.2 100.0 85.3 66.9
75 52.0 61.0 91.0 20.0 96.3 99.5 99.5 99.8 42.8 77.4
100.0 56.4 21.9 0.0 100.0 0.0 0.0 87.3 100.0 100.0 88.8
81.8 93.5 0.0 91.2
76 2.9 0.0 54.9 0.0 63.3 98.5 99.5 98.2 47.4 100.0
56.1 100.0 100.0 0.0 9.0 0.0 0.0 100.0 88.3 100.0 87.8
9.1 97.9 100.0 0.0
77 100.0 86.4 99.1 94.7 84.7 97.0 0.0 90.0 78.9 89.3
100.0 17.2 12.6 0.0 6.0 19.9 73.3 100.0 93.3 0.0 70.8
68.2 82.7 76.9 54.9
78 100.0 100.0 99.8 94.7 26.0 100.0 58.5 100.0 0.0 0.0
100.0 73.7 0.0 0.0 6.0 0.0 57.9 0.0 100.0 100.0 0.0
95.5 46.1 56.8 13.0
79 18.1 16.8 49.5 0.0 77.0 59.5 99.4 80.6 80.5 100.0
89.7 100.0 94.2 0.0 100.0 0.0 0.0 100.0 99.6 100.0 99.7
86.4 84.2 96.8 96.2
80 97.7 100.0 96.4 94.7 81.6 100.0 75.5 100.0 0.0 88.9
100.0 2.9 0.0 0.0 0.0 91.0 65.1 98.9 77.0 100.0 93.3
90.9 93.9 0.0 28.1
81 89.5 64.3 97.3 29.4 29.5 100.0 96.1 100.0 77.6 81.8
51.5 97.6 50.8 100.0 2.0 79.9 84.6 95.1 79.5 100.0 99.6
81.8 100.0 99.7 57.1
82 83.9 88.1 98.2 94.7 100.0 100.0 96.7 100.0 96.2 94.1
100.0 13.0 7.3 0.0 26.0 50.3 77.9 100.0 43.9 54.8 98.2
100.0 91.7 88.4 86.0
83 100.0 100.0 99.6 94.7 100.0 99.4 82.3 100.0 42.3 100.0
100.0 66.9 46.5 0.0 100.0 0.0 0.0 100.0 100.0 22.8 92.4
95.5 54.3 57.9 64.6
84 74.3 98.3 99.5 89.3 100.0 100.0 99.0 100.0 96.0 100.0
100.0 61.3 42.1 0.0 1.0 85.0 65.1 100.0 71.9 49.5 98.0
95.5 93.4 84.8 82.5
85 68.4 67.7 87.4 94.5 100.0 100.0 98.5 100.0 41.9 47.5
100.0 30.4 9.9 0.0 2.0 55.1 87.2 36.3 7.2 100.0 93.7
86.4 99.4 83.9 16.1
86 62.6 86.4 99.3 33.7 84.1 100.0 99.1 100.0 31.7 39.6
100.0 3.0 1.7 0.0 100.0 0.0 0.0 97.0 0.0 100.0 0.0
95.5 98.6 60.3 44.4
87 20.5 15.1 40.5 0.0 78.7 100.0 99.6 100.0 29.4 86.9
93.7 54.5 25.1 59.4 2.0 72.1 0.0 97.8 99.7 98.6 71.6
72.7 98.2 93.7 47.5
88 75.4 94.9 96.4 85.1 83.7 98.0 94.7 82.8 51.7 65.2
95.1 76.9 48.1 31.0 11.0 79.2 100.0 78.4 84.7 63.6 79.7
81.8 91.1 78.9 44.5
89 68.6 74.8 92.8 68.4 99.7 100.0 92.2 100.0 39.4 100.0
100.0 20.2 11.4 0.0 100.0 0.0 0.0 100.0 100.0 100.0 67.0
45.5 94.3 71.6 30.5
90 36.8 15.1 4.5 0.0 0.0 93.1 99.8 92.6 68.6 85.1
82.9 56.5 17.9 0.0 100.0 0.0 0.0 80.0 100.0 100.0 95.9
18.2 93.7 100.0 53.4
91 73.1 62.6 73.0 0.0 58.9 91.4 99.5 63.2 69.2 97.9
88.9 29.3 45.6 16.7 2.0 0.0 0.0 96.1 99.6 100.0 95.3
81.8 93.2 67.5 60.7

92 52.0 35.5 80.2 46.3 59.2 100.0 97.0 100.0 44.6 87.6
83.0 100.0 76.1 0.0 100.0 0.0 0.0 77.7 99.8 100.0 87.4
77.3 75.9 54.0 42.5
93 20.5 3.2 15.3 15.8 84.0 98.3 99.4 97.2 29.4 85.2
94.4 99.8 92.8 0.0 20.0 72.3 38.4 98.3 99.9 100.0 16.4
4.5 99.4 100.0 99.9
94 22.8 20.2 31.5 40.7 30.0 100.0 99.6 100.0 20.1 82.5
30.9 64.0 4.3 0.0 40.0 68.1 84.6 32.5 100.0 100.0 99.7
13.6 59.4 80.5 31.1
95 93.0 100.0 98.2 94.7 100.0 100.0 88.8 100.0 29.4 100.0
87.4 12.6 0.0 75.0 0.0 99.1 100.0 0.0 0.0 100.0 0.0
95.5 36.8 91.1 32.6
96 54.4 54.2 15.3 0.0 77.7 100.0 99.3 100.0 29.4 84.7
79.8 91.7 78.6 100.0 100.0 0.0 0.0 99.6 97.5 100.0 72.3
0.0 97.8 96.1 89.6
97 93.0 98.3 98.2 94.7 92.5 100.0 95.9 99.9 69.6 99.2
100.0 99.4 97.3 66.7 10.0 5.7 100.0 100.0 97.1 96.0 99.9
90.9 73.7 72.0 40.0
98 12.3 77.9 76.6 32.1 81.0 0.0 98.7 72.7 29.4 42.6
79.6 100.0 97.8 0.0 0.0 54.8 100.0 48.7 100.0 100.0 94.3
13.6 92.4 100.0 97.2
99 0.0 8.3 0.0 0.0 0.0 99.6 99.8 99.6 21.4 68.4 82.3
99.7 66.3 0.0 100.0 0.0 0.0 34.5 36.1 100.0 99.8 59.1
94.2 96.5 30.1
100 34.5 11.7 42.3 29.5 60.5 93.8 97.9 32.3 20.1 94.9
38.8 52.9 41.0 100.0 0.0 52.2 50.7 94.1 57.0 100.0 92.2
13.6 100.0 100.0 56.6
101 38.0 64.3 85.6 32.2 90.8 100.0 98.9 100.0 57.1 100.0
72.2 70.6 62.9 0.0 1.0 91.9 100.0 100.0 92.2 100.0 98.6
22.7 94.5 91.2 41.9
102 100.0 100.0 99.6 94.7 88.1 99.7 32.8 99.7 64.2 73.4
100.0 19.7 3.7 0.0 4.0 0.0 94.4 100.0 85.1 22.8 92.9
95.5 78.1 61.9 58.3
103 100.0 100.0 99.6 94.7 100.0 100.0 86.8 100.0 91.2 100.0
100.0 81.3 59.3 0.0 43.0 48.9 92.8 100.0 86.2 0.0 99.2
100.0 79.9 98.9 99.4
104 24.0 83.0 63.9 14.7 84.3 99.9 98.5 99.8 53.9 99.0
70.3 40.6 49.3 0.0 100.0 0.0 0.0 100.0 87.5 100.0 83.7
59.1 97.2 97.3 99.9
105 100.0 100.0 99.1 94.7 100.0 100.0 96.1 100.0 99.0 98.7
100.0 82.3 84.9 78.6 2.0 72.7 100.0 100.0 97.4 93.6 96.5
100.0 60.3 82.7 70.4
106 86.0 69.4 98.2 94.7 16.3 100.0 96.1 100.0 0.0 58.6
100.0 91.8 91.8 0.0 1.0 69.0 100.0 64.6 93.1 100.0 95.8
13.6 76.6 76.4 7.8
107 52.0 84.7 60.3 14.7 9.1 99.8 97.6 97.9 41.2 63.2
46.0 95.6 46.7 0.0 9.0 67.8 89.2 94.4 45.8 100.0 97.2
9.1 100.0 43.1 59.0
108 68.4 83.0 94.6 65.3 86.1 99.8 96.1 100.0 75.7 97.2
75.3 93.9 93.1 50.0 20.0 82.9 100.0 100.0 100.0 100.0 99.9
95.5 89.7 74.0 70.1
109 56.7 71.1 89.2 65.1 62.3 99.6 94.8 98.9 33.8 81.6
100.0 98.1 79.6 32.3 2.0 77.1 51.3 67.5 99.8 40.2 85.1
95.5 94.0 88.8 78.7
110 67.3 74.5 91.0 53.1 89.7 100.0 94.5 100.0 40.6 96.7
57.5 94.0 41.4 36.4 6.0 52.5 85.1 98.9 89.1 54.4 99.9
81.8 100.0 99.3 46.6
111 34.5 0.0 76.6 5.6 100.0 100.0 99.7 100.0 0.0 98.1
89.5 89.4 81.5 16.7 1.0 95.7 100.0 0.0 100.0 100.0 99.9
4.5 88.8 93.6 45.3

112 84.2 88.4 98.2 94.7 84.9 100.0 71.0 99.9 68.1 93.9
100.0 67.5 33.3 0.0 7.0 58.9 66.1 100.0 40.7 89.8 95.9
95.5 84.5 74.5 29.0
113 100.0 100.0 99.1 94.7 94.8 98.7 94.6 99.1 86.2 89.0
100.0 26.7 7.1 100.0 1.0 95.1 100.0 100.0 69.2 23.0 82.5
95.5 88.9 83.5 46.3
114 76.6 76.2 91.0 44.4 32.2 20.3 98.8 61.2 49.6 74.1
76.7 69.3 47.7 0.0 100.0 0.0 0.0 100.0 95.0 100.0 86.4
95.5 82.6 100.0 100.0
115 43.3 27.0 92.8 75.9 100.0 100.0 90.9 100.0 51.3 81.0
100.0 32.8 22.2 0.0 71.0 98.1 48.2 91.6 33.1 22.7 54.4
100.0 92.5 61.2 57.5
116 84.8 94.9 99.5 90.7 100.0 100.0 92.5 99.8 48.3 97.7
100.0 87.9 74.5 100.0 26.0 83.9 0.0 96.3 57.0 87.5 74.6
0.0 74.5 50.7 63.6
117 32.2 55.9 15.3 0.0 85.9 99.8 98.1 99.8 25.6 100.0
100.0 74.6 69.7 0.0 100.0 0.0 0.0 100.0 78.8 100.0 93.2
18.2 95.6 100.0 38.3
118 85.3 86.4 98.2 94.7 4.7 99.9 98.1 99.8 0.0 43.0
100.0 100.0 100.0 0.0 20.0 55.5 100.0 0.0 61.2 100.0 97.2
90.9 70.4 61.8 19.4
119 22.8 49.1 67.6 0.0 0.0 84.8 99.6 54.6 45.2 88.2
81.7 30.1 31.2 0.0 0.0 78.6 0.0 55.4 98.2 100.0 24.9
95.5 95.2 100.0 8.6
120 49.7 59.3 60.3 44.2 53.1 97.5 99.4 97.7 49.6 85.3
89.4 39.1 44.2 0.0 4.0 73.9 92.8 98.6 96.2 100.0 67.0
18.2 100.0 80.5 31.7
121 19.3 49.1 74.8 0.0 86.6 100.0 99.9 100.0 14.7 100.0
47.2 6.5 0.6 0.0 0.0 95.2 0.0 0.0 0.0 100.0 0.0 4.5
0.0 92.3 30.1
122 28.7 27.0 0.0 3.2 70.0 78.0 99.1 90.9 20.1 100.0
84.1 12.9 5.0 0.0 0.0 73.7 100.0 100.0 100.0 100.0 84.9
4.5 89.4 89.4 30.1
123 55.6 72.8 91.0 65.3 87.0 100.0 95.8 100.0 57.1 100.0
47.2 12.4 0.6 0.0 0.0 76.6 100.0 100.0 49.9 100.0 98.7
77.3 100.0 94.0 71.6
124 98.8 100.0 99.6 94.7 100.0 100.0 81.8 100.0 51.3 100.0
100.0 59.7 47.3 0.0 100.0 0.0 0.0 100.0 51.9 56.7 83.9
100.0 86.4 52.3 75.0
125 100.0 100.0 99.1 91.6 91.2 99.0 89.3 99.9 96.0 100.0
100.0 60.4 13.3 0.0 5.0 0.0 100.0 100.0 96.3 10.0 91.4
86.4 84.4 82.4 64.6
126 100.0 100.0 99.8 94.7 100.0 99.8 96.3 99.9 94.6 99.6
100.0 75.8 52.3 0.0 26.0 76.8 80.0 100.0 75.0 22.8 98.9
100.0 89.8 89.9 95.1
127 39.2 35.5 69.4 32.8 88.0 99.1 99.2 99.9 29.4 95.6
95.5 100.0 1.2 0.0 100.0 0.0 0.0 100.0 100.0 100.0 61.0
4.5 27.6 93.0 41.6
128 88.3 88.1 92.8 66.3 44.4 100.0 95.3 100.0 0.0 38.7
100.0 21.1 2.8 0.0 4.0 71.4 0.0 89.3 8.0 100.0 93.8
95.5 97.1 45.4 36.7
129 0.0 1.5 27.9 0.0 10.2 65.6 99.7 74.1 21.8 81.9
86.4 86.6 73.3 0.0 100.0 0.0 0.0 86.9 100.0 100.0 66.9
54.5 89.7 100.0 30.1
130 24.0 18.5 67.6 8.1 80.3 80.8 99.0 91.7 20.1 100.0
0.0 100.0 38.7 0.0 1.0 65.8 100.0 100.0 47.0 100.0 82.5
72.7 98.3 100.0 48.9
131 98.8 98.3 96.4 24.2 55.1 94.0 93.9 65.3 79.7 90.3
91.4 64.6 73.4 0.0 14.0 20.3 100.0 100.0 81.5 90.8 98.3
90.9 92.8 77.8 42.8

132 42.7 30.4 82.0 0.0 70.9 99.4 99.8 99.8 42.8 84.6
83.5 58.3 29.3 0.0 100.0 0.0 0.0 93.1 98.9 100.0 94.8
13.6 97.6 100.0 97.1
133 55.6 52.5 87.4 94.7 64.7 100.0 99.5 100.0 42.8 69.2
100.0 99.2 16.9 0.0 100.0 0.0 0.0 83.5 96.7 100.0 99.2
0.0 60.4 100.0 14.3
134 100.0 84.7 98.2 91.6 20.5 100.0 81.2 100.0 59.4 100.0
100.0 98.8 41.1 50.0 0.0 84.4 98.5 100.0 74.7 100.0 0.0
86.4 62.5 0.0 23.6
135 82.5 88.1 96.4 94.7 88.9 100.0 94.7 100.0 39.7 42.7
100.0 50.3 8.9 0.0 1.0 6.3 100.0 76.8 0.0 75.7 99.1
13.6 97.2 86.1 48.0
136 86.0 93.2 94.6 88.4 76.7 100.0 93.6 100.0 54.0 84.7
100.0 10.8 2.8 0.0 11.0 34.4 62.5 96.8 77.6 42.1 87.5
86.4 95.7 50.4 53.3
137 100.0 100.0 99.8 100.0 66.6 99.8 0.0 99.7 42.3 100.0
0.0 100.0 100.0 0.0 0.0 19.2 100.0 100.0 100.0 13.9 100.0
0.0 82.3 82.5 31.9
138 38.0 35.5 53.1 21.6 93.0 99.6 99.6 98.9 48.0 88.0
73.3 100.0 92.8 88.9 14.0 83.3 74.9 77.4 99.9 100.0 33.5
18.2 97.5 86.3 34.6
139 33.3 32.1 36.9 0.0 100.0 99.4 99.3 98.8 28.0 98.5
52.4 99.9 87.0 50.0 100.0 0.0 0.0 100.0 49.5 98.1 20.0
4.5 100.0 100.0 83.6
140 95.3 93.2 99.5 93.2 93.8 100.0 93.8 100.0 31.7 73.3
100.0 9.7 5.5 0.0 16.0 77.0 78.4 84.4 1.5 100.0 17.8
72.7 87.2 0.0 66.1
141 100.0 100.0 98.2 94.7 3.9 99.5 99.3 99.9 80.5 100.0
100.0 1.0 0.2 0.0 0.0 35.2 100.0 100.0 100.0 89.7 99.0
54.5 76.6 100.0 88.9
142 100.0 100.0 99.6 94.7 97.8 89.2 88.0 0.0 69.7 76.5
100.0 74.7 84.9 58.3 38.0 75.1 69.7 77.5 73.4 65.7 86.6
86.4 56.3 73.7 38.2
143 61.4 69.4 98.2 24.2 53.3 100.0 95.8 99.9 42.8 53.5
100.0 36.2 11.6 0.0 100.0 0.0 0.0 75.2 66.8 100.0 93.9
0.0 88.5 0.0 52.2
144 62.6 71.1 94.6 94.7 100.0 99.5 96.1 99.0 49.6 89.3
87.7 100.0 91.5 55.6 32.0 68.4 81.0 75.0 98.6 0.5 91.6
13.6 78.4 50.9 75.7
145 54.4 74.5 92.8 26.7 62.0 98.8 98.1 91.6 78.5 96.7
100.0 28.5 25.7 58.3 1.0 6.5 100.0 100.0 81.4 63.6 97.9
90.9 98.8 69.2 56.2
146 33.3 44.0 47.7 56.2 40.4 100.0 96.6 100.0 0.0 38.3
100.0 0.3 0.1 0.0 2.0 66.7 100.0 0.0 72.6 100.0 90.9
90.9 100.0 74.6 8.9
147 59.1 79.6 83.8 81.2 94.8 98.9 84.9 95.8 44.0 39.5
100.0 77.0 43.3 50.0 4.0 70.5 100.0 56.0 92.4 100.0 61.4
63.6 86.4 59.1 8.6
148 47.4 28.7 24.3 8.1 67.9 31.9 96.7 33.9 29.4 99.9
77.9 100.0 99.7 0.0 100.0 0.0 0.0 100.0 99.9 100.0 0.0
40.9 81.2 62.6 99.3
149 45.0 67.7 74.8 24.6 93.0 91.1 98.9 89.8 29.4 77.5
64.4 100.0 98.3 75.0 100.0 0.0 0.0 98.3 99.6 100.0 67.2
0.0 96.8 69.3 38.3
;

Parameters
U(i) upper bound for weight i /
1 0.25
2 0.25

```
3       0.25
4       0.25
5       0.25
6       0.25
7       0.25
8       0.25
9       0.25
10      0.25
11      0.25
12      0.25
13      0.25
14      0.25
15      0.25
16      0.25
17      0.25
18      0.25
19      0.25
20      0.25
21      0.25
22      0.25
23      0.25
24      0.25
25      0.25 /

L(i)    lower bound for weight i /
1       0.005
2       0.005
3       0.005
4       0.005
5       0.005
6       0.005
7       0.005
8       0.005
9       0.005
10      0.005
11      0.005
12      0.005
13      0.005
14      0.005
15      0.005
16      0.005
17      0.005
18      0.005
19      0.005
20      0.005
21      0.005
22      0.005
23      0.005
24      0.005
25      0.005 / ;

Variables
        w(i)    weight of indicator i
        R       ranking of the country
        c       Score
        z       result ;

Positive variable w;

Binary variable x(j) country rank calculator;
```

```
Equations
        Rank           Determining final rank
        Large(j)       Finding larger score countries
        Terslarge(j)   Score condition
        Lower(i)       Lower bound for weight i
        Upper(i)       Upper bound for weight i
        Weights1       Weight relations 1
        Weights2       Weight relations 2
        Weights3       Weight relations 3
        Weights4       Weight relations 4
        Weights5       Weight relations 5
        Weights6       Weight relations 6
        Weights7       Weight relations 7
        Weights8       Weight relations 8
        Sumup          Hundred percent
        Score          Total Score
        Func           Objective function;
Rank..            Sum(j, x(j)) + 1 =e= R;
Large(j)..        Sum(i, w(i)*S(j,i)) - Sum(i, w(i)*S('136',i)) =l= 100 * x(j);
Terslarge(j)..    Sum(i, w(i)*S('136',i)) - Sum(i, w(i)*S(j,i)) =l= 100 * (1-x(j));
Lower(i)..        w(i)=g= L(i);
Upper(i)..        w(i)=l= U(i);
Weights1..        w('3') =e= 0.25;
Weights2..        w('1')+w('2') =e= 0.125;
Weights3..        w('4')+w('5')+w('6') =e= 0.125;
Weights4..        w('7')+w('8') =e= 0.025;
Weights5..        w('9')+w('10') =e= 0.075;
Weights6..        w('12')+w('13')+w('14')+w('15') =e= 0.075;
Weights7..        w('11')+w('16')+w('17')+w('18')+w('19')+w('20')+w('21')+w('22') =e= 0.075;
Weights8..        w('23')+w('24')+w('25') =e= 0.25;
Sumup..           Sum(i, w(i)) =e= 1;
Score..           c =e= Sum(i, w(i)*S('136',i));
Func..            z =e= R ;

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip minimizing z;
File result /D:\TEZ\Outputf\cikti.txt/;

Put result;
Put
        @10, 'Rank', R.l,
        @10#2, 'Score', c.l,
        @10#3, 'Weights'/;
        loop(i, put @1, i.tl, @5, w.l(i)/);
```

C.2 Model 1.2

```
$Title Model 1.2

Sets    j      countries /1*149/
        i      indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators “defined in Model 1.1” ;

Parameters
U(i)    upper bound for weight i /
1       0.25
2       0.25
3       0.25
4       0.25
5       0.25
6       0.25
7       0.25
8       0.25
9       0.25
10       0.25
11       0.25
12       0.25
13       0.25
14       0.25
15       0.25
16       0.25
17       0.25
18       0.25
19       0.25
20       0.25
21       0.25
22       0.25
23       0.25
24       0.25
25       0.25 /

L(i)    lower bound for weight i /
1       0.005
2       0.005
3       0.005
4       0.005
5       0.005
6       0.005
7       0.005
8       0.005
9       0.005
10       0.005
11       0.005
12       0.005
13       0.005
14       0.005
15       0.005
16       0.005
17       0.005
18       0.005
19       0.005
20       0.005
21       0.005
22       0.005
```

```
23       0.005
24       0.005
25       0.005 / ;

Variables
        w(i)    weight of indicator i
        R       ranking of the country
        c       Score
        z       result ;

Binary variable x(j) country rank calculator;

Equations

        Rank           Determining final rank
        Large(j)       Finding larger score countries
        Terslarge(j)   Score condition
        Lower(i)       Lower bound for weight i
        Upper(i)       Upper bound for weight i
        Weights1       Weight relations 1
        Weights2       Weight relations 2
        Weights3       Weight relations 3
        Weights4       Weight relations 4
        Weights5       Weight relations 5
        Weights6       Weight relations 6
        Weights7       Weight relations 7
        Weights8       Weight relations 8
        Sumup          Hundred percent
        Score          Total Score
        Func           Objective function;

Rank..              Sum(j, x(j)) + 1 =e= R;
Large(j)..          Sum(i, w(i)*S(j,i)) - Sum(i, w(i)*S('136',i)) =l= 100 * x(j);
Terslarge(j)..      Sum(i, w(i)*S('136',i)) - Sum(i, w(i)*S(j,i)) =l= 100 * (1-x(j));
Lower(i)..          w(i)=g= L(i);
Upper(i)..          w(i)=l= U(i);
Weights1..          w('3') =e= 0.25;
Weights2..          w('1')+w('2') =e= 0.125;
Weights3..          w('4')+w('5')+w('6') =e= 0.125;
Weights4..          w('7')+w('8') =e= 0.025;
Weights5..          w('9')+w('10') =e= 0.075;
Weights6..          w('12')+w('13')+w('14')+w('15') =e= 0.075;
Weights7..          w('11')+w('16')+w('17')+w('18')+w('19')+w('20')+w('21')+w('22') =e= 0.075;
Weights8..          w('23')+w('24')+w('25') =e= 0.25;
Sumup..             Sum(i, w(i)) =e= 1;
Score..             c =e= Sum(i, w(i)*S('136',i));
Func..              z =e= R;
Model Rashid /all/;

Option DNLP=CONOPT;
Solve Rashid using mip maximizing z;

File result /D:\TEZ\Outputf\cikti.txt/;
Put result ;

Put
        @10, 'Rank', z.l,
        @10#2, 'Score', c.l,
        @10#3, 'Weights'/;
        loop(j, put @1, j.tl, @5, x.l(j)/);
```

C.3 Model 1.3

```
$Title Model 1.3

Sets    j      countries /1*149/
        i      indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators "defined in Model 1.1" ;

Scalar   R country rank /40/ ;

Parameters
U(i)    upper bound for weight i /
1       0.5
2       0.5
3       0.5
4       0.5
5       0.5
6       0.5
7       0.5
8       0.5
9       0.5
10      0.5
11      0.5
12      0.5
13      0.5
14      0.5
15      0.5
16      0.5
17      0.5
18      0.5
19      0.5
20      0.5
21      0.5
22      0.5
23      0.5
24      0.5
25      0.5 /

L(i)    lower bound for weight i /
1       0.005
2       0.005
3       0.005
4       0.005
5       0.005
6       0.005
7       0.005
8       0.005
9       0.005
10      0.005
11      0.005
12      0.005
13      0.005
14      0.005
15      0.005
16      0.005
17      0.005
18      0.005
19      0.005
20      0.005
```

```
21      0.005
22      0.005
23      0.005
24      0.005
25      0.005 / ;

Variables
        w(i)    weight of indicator i
        c       Score
        z       result ;

Positive variable w;

Binary variable x(j) country rank calculator;

Equations
        Rank            Determining final rank
        Large(j)        Finding larger score countries
        Terslarge(j)    Score condition
        Lower(i)        Lower bound for weight i
        Upper(i)        Upper bound for weight i
        Weights1        Weight relations 1
        Weights2        Weight relations 2
        Weights3        Weight relations 3
        Weights4        Weight relations 4
        Weights5        Weight relations 5
        Weights6        Weight relations 6
        Weights7        Weight relations 7
        Weights8        Weight relations 8
        Sumup           Sum of weights
        Score           Total Score
        Func            Objective function  ;

Rank..            Sum(j, x(j)) + 1 =e= R;
Large(j)..        Sum(i, w(i)*S(j,i)) - Sum(i, w(i)*S('136',i)) =l= 100 * x(j);
Terslarge(j)..    Sum(i, w(i)*S('136',i)) - Sum(i, w(i)*S(j,i)) =l= 100 * (1-x(j));
Lower(i)..        w(i)=g= L(i);
Upper(i)..        w(i)=l= U(i);
Weights1..        w('3') =e= 0.25;
Weights2..        w('1')+w('2') =e= 0.125;
Weights3..        w('4')+w('5')+w('6') =e= 0.125;
Weights4..        w('7')+w('8') =e= 0.025;
Weights5..        w('9')+w('10') =e= 0.075;
Weights6..        w('12')+w('13')+w('14')+w('15') =e= 0.075;
Weights7..        w('11')+w('16')+w('17')+w('18')+w('19')+w('20')+w('21')+w('22') =e= 0.075;
Weights8..        w('23')+w('24')+w('25') =e= 0.25;
Sumup..           Sum(i, w(i)) =e= 1;
Score..           c =e= Sum(i, w(i)*S('136',i));
Func..            z =e= 0;
Model Rashid /all/;
Option DNLP=CONOPT;
Solve Rashid using mip maximizing z;
File result /D:\TEZ\Outputf\cikti.txt/;
Put result ;

Put
        @10, 'Rank', R,
        @10#2, 'Score', c.l,
        @10#3,  'Weights'/;
        loop(i, put @1, i.tl, @5, w.l(i)/);
```

C.4 Model 1.4

```
$Title Model 1.4

Sets   j      countries /1*149/
       i      indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators "defined in Model 1.1" ;

Parameters

U(i)    upper bound for weight i /
1       0.25
2       0.25
3       0.25
4       0.25
5       0.25
6       0.25
7       0.25
8       0.25
9       0.25
10       0.25
11       0.25
12       0.25
13       0.25
14       0.25
15       0.25
16       0.25
17       0.25
18       0.25
19       0.25
20       0.25
21       0.25
22       0.25
23       0.25
24       0.25
25       0.25/

L(i)    lower bound for weight i /
1       0.005
2       0.005
3       0.005
4       0.005
5       0.005
6       0.005
7       0.005
8       0.005
9       0.005
10       0.005
11       0.005
12       0.005
13       0.005
14       0.005
15       0.005
16       0.005
17       0.005
18       0.005
19       0.005
20       0.005
21       0.005
```

```
22      0.005
23      0.005
24      0.005
25      0.005 / ;

Variables
        w(i)    weight of indicator i
        c       Score
        z       result ;

Positive variable w;

Binary variable x(j) country rank calculator;

Equations
        Lower(i)        Lower bound for weight i
        Upper(i)        Upper bound for weight i
        Weights1        Weight relations 1
        Weights2        Weight relations 2
        Weights3        Weight relations 3
        Weights4        Weight relations 4
        Weights5        Weight relations 5
        Weights6        Weight relations 6
        Weights7        Weight relations 7
        Weights8        Weight relations 8
        Sumup           Hundred percent
        Score           Total Score
        Func            Objective function;

Lower(i)..          w(i)=g= L(i);
Upper(i)..          w(i)=l= U(i);
Weights1..          w('3') =e= 0.25;
Weights2..          w('1')+w('2') =e= 0.125;
Weights3..          w('4')+w('5')+w('6') =e= 0.125;
Weights4..          w('7')+w('8') =e= 0.025;
Weights5..          w('9')+w('10') =e= 0.075;
Weights6..          w('12')+w('13')+w('14')+w('15') =e= 0.075;
Weights7..          w('11')+w('16')+w('17')+w('18')+w('19')+w('20')+w('21')+w('22') =e= 0.075;
Weights8..          w('23')+w('24')+w('25') =e= 0.25;
Sumup..             Sum(i, w(i)) =e= 1;
Score..             c =e= Sum(i, w(i)*S('136',i));
Func..              z =e= c ;

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip maximizing z;

File  result /D:\TEZ\Outputf\cikti.txt/;

Put  result ;

Put
        @10#2, 'Score', c.l,
        @10#3, 'Weights'/;
        loop(i, put @1, i.tl, @5, w.l(i)/);
```

C.5 Model 1.5

```
$Title Model 1.5

Sets    j       countries /1*149/
        i       indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators "defined in Model 1.1" ;

Parameters
U(i)    upper bound for weight i /
1       0.25
2       0.25
3       0.25
4       0.25
5       0.25
6       0.25
7       0.25
8       0.25
9       0.25
10      0.25
11      0.25
12      0.25
13      0.25
14      0.25
15      0.25
16      0.25
17      0.25
18      0.25
19      0.25
20      0.25
21      0.25
22      0.25
23      0.25
24      0.25
25      0.25 /
L(i)    lower bound for weight i /
1       0.005
2       0.005
3       0.005
4       0.005
5       0.005
6       0.005
7       0.005
8       0.005
9       0.005
10      0.005
11      0.005
12      0.005
13      0.005
14      0.005
15      0.005
16      0.005
17      0.005
18      0.005
19      0.005
20      0.005
21      0.005
22      0.005
23      0.005
```

```
24      0.005
25      0.005 / ;
Variables
        w(i)    weight of indicator i
        c       Score
        z       result ;

Positive variable w;

Binary variable x(j) country rank calculator;

Equations
        Lower(i)        Lower bound for weight i
        Upper(i)        Upper bound for weight i
        Weights1        Weight relations 1
        Weights2        Weight relations 2
        Weights3        Weight relations 3
        Weights4        Weight relations 4
        Weights5        Weight relations 5
        Weights6        Weight relations 6
        Weights7        Weight relations 7
        Weights8        Weight relations 8
        Sumup           Hundred percent
        Score           Total Score
        Func            Objective function;

Lower(i)..          w(i)=g= L(i);
Upper(i)..          w(i)=l= U(i);
Weights1..          w('3') =e= 0.25;
Weights2..          w('1')+w('2') =e= 0.125;
Weights3..          w('4')+w('5')+w('6') =e= 0.125;
Weights4..          w('7')+w('8') =e= 0.025;
Weights5..          w('9')+w('10') =e= 0.075;
Weights6..          w('12')+w('13')+w('14')+w('15') =e= 0.075;
Weights7..          w('11')+w('16')+w('17')+w('18')+w('19')+w('20')+w('21')+w('22') =e= 0.075;
Weights8..          w('23')+w('24')+w('25') =e= 0.25;
Sumup..             Sum(i, w(i)) =e= 1;
Score..             c =e= Sum(i, w(i)*S('136',i));
Func..              z =e= c ;

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip minimizing z;

File  result /D:\TEZ\Outputf\cikti.txt/;

Put  result ;

Put
        @10#2, 'Score', c.l,
        @10#3, 'Weights'/;
        loop(i, put @1, i.tl, @5, w.l(i)/);
```

C.6 Model 2.1

```
$Title Model 2.1

Sets    j      countries /1*148/
        i      indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators “defined in Model 1.1” ;

Parameters
U(i)    upper bound for Scores of country n /
1       100.0
2       100.0
3       100.0
4       100.0
5       100.0
6       100.0
7       100.0
8       100.0
9       100.0
10      100.0
11      100.0
12      100.0
13      100.0
14      100.0
15      100.0
16      100.0
17      100.0
18      100.0
19      100.0
20      100.0
21      100.0
22      100.0
23      100.0
24      100.0
25      100.0/
L(i)    lower bound for Scores of country n /
1   85.96
2   93.21
3   94.59
4   88.42
5   76.73
6   99.99
7   93.61
8   99.95
9   53.97
10  84.66
11 100.00
12  10.81
13   2.82
14   0.00
15  11.00
16  34.37
17  62.50
18  96.82
19  77.56
20  42.12
21  87.49
22  86.36
23  95.67
```

```
24  50.43
25  53.32 /
W(i)    weight i /
1       0.0625
2       0.0625
3       0.25
4       0.05
5       0.05
6       0.025
7       0.0125
8       0.0125
9       0.0375
10      0.0375
11      0.025
12      0.0188
13      0.0188
14      0.0188
15      0.0188
16      0.0125
17      0.0125
18      0.005
19      0.005
20      0.005
21      0.005
22      0.005
23      0.0833
24      0.0833
25      0.0833 / ;

Variables
        G(i) score vector of country n
        z         result ;

Equations
        Lower(i)       Lower bound for weight i
        Upper(i)       Upper bound for weight i
        Func           Objective function ;

Lower(i)..             G(i)=g= L(i);
Upper(i)..             G(i)=l= U(i);
Func..                 z =e= Sum(i, w(i)*G(i));

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip maximizing z;

File result /D:\TEZ\Outputf\cikti.txt/;

Put result ;

Put
        @10, 'Score', z.l;
        loop(i, put @1, i.tl, @5, G.l(i)/);
```

C.7 Model 2.2

```
$Title Model 2.2

Sets    j       countries /1*148/
        i       indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators "defined in Model 1.1" ;

Parameters
U(i)    upper bound for Scores of country n /
1        100.0
2        100.0
3        100.0
4        100.0
5        100.0
6        100.0
7        100.0
8        100.0
9        100.0
10       100.0
11       100.0
12       100.0
13       100.0
14       100.0
15       100.0
16       100.0
17       100.0
18       100.0
19       100.0
20       100.0
21       100.0
22       100.0
23       100.0
24       100.0
25       100.0 /
L(i)    lower bound for Scores of country n /
1   85.96
2   93.21
3   94.59
4   88.42
5   76.73
6   99.99
7   93.61
8   99.95
9   53.97
10  84.66
11 100.00
12  10.81
13   2.82
14   0.00
15  11.00
16  34.37
17  62.50
18  96.82
19  77.56
20  42.12
21  87.49
22  86.36
23  95.67
```

```
24  50.43
25  53.32 /
W(i)    weight i /
1       0.0625
2       0.0625
3       0.25
4       0.05
5       0.05
6       0.025
7       0.0125
8       0.0125
9       0.0375
10       0.0375
11       0.025
12       0.0188
13       0.0188
14       0.0188
15       0.0188
16       0.0125
17       0.0125
18       0.005
19       0.005
20       0.005
21       0.005
22       0.005
23       0.0833
24       0.0833
25       0.0833 / ;

Variables
        G(i) score vector of country n
        z          result ;

Equations
        Lower(i)       Lower bound for weight i
        Upper(i)       Upper bound for weight i
        Func           Objective function ;

Lower(i)..              G(i)=g= L(i);
Upper(i)..              G(i)=l= U(i);
Func..                  z =e= Sum(i, w(i)*G(i));

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip minimizing z;

File result /D:\TEZ\Outputf\cikti.txt/;

Put result ;

Put
        @10, 'Score', z.l;
        loop(i, put @1, i.tl, @5, G.l(i)/);
```

C.8 Model 2.3

```
$Title Model 2.3

Sets    j       countries /1*148/
        i       indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators "defined in Model 1.1" ;

Scalar   R country rank /40/

Parameters
U(i)    upper bound for Scores of country n /
1        100.0
2        100.0
3        100.0
4        100.0
5        100.0
6        100.0
7        100.0
8        100.0
9        100.0
10       100.0
11       100.0
12       100.0
13       100.0
14       100.0
15       100.0
16       100.0
17       100.0
18       100.0
19       100.0
20       100.0
21       100.0
22       100.0
23       100.0
24       100.0
25       100.0 /
L(i)    lower bound for Scores of country n /
1   85.96
2   93.21
3   94.59
4   88.42
5   76.73
6   99.99
7   93.61
8   99.95
9   53.97
10  84.66
11 100.00
12  10.81
13   2.82
14   0.00
15  11.00
16  34.37
17  62.50
18  96.82
19  77.56
20  42.12
21  87.49
```

```
22  86.36
23  95.67
24  50.43
25  53.32 /
W(i)    weight i /
1        0.0625
2        0.0625
3        0.25
4        0.05
5        0.05
6        0.025
7        0.0125
8        0.0125
9        0.0375
10       0.0375
11       0.025
12       0.0188
13       0.0188
14       0.0188
15       0.0188
16       0.0125
17       0.0125
18       0.005
19       0.005
20       0.005
21       0.005
22       0.005
23       0.0833
24       0.0833
25       0.0833 / ;
Variables
        G(i) score vector of country n
        C    Total Score
        z          result ;
Binary variable x(j) country rank calculator;

Equations
        Rank           Determining final rank
        Large(j)       Finding larger score countries
        Terslarge(j)    Score condition
        Lower(i)        Lower bound for weight i
        Upper(i)        Upper bound for weight i
        Score          Total Score
        Func           Objective function;
Rank..                 Sum(j, x(j)) + 1 =e= R;
Large(j)..             Sum(i, w(i)*S(j,i)) - Sum(i, w(i)*G(i)) =l= 100 * x(j);
Terslarge(j)..           Sum(i, w(i)*G(i)) - Sum(i, w(i)*S(j,i)) =l= 100 * (1-x(j));
Lower(i)..              G(i)=g= L(i);
Upper(i)..             G(i)=l= U(i);
Score..                Sum(i, w(i)*G(i)) =e= C;
Func..                 z =e= 0  ;
Model Rashid /all/;
Option DNLP=CONOPT;
Solve Rashid using mip maximizing z;
File result /D:\TEZ\Outputf\cikti.txt/;
Put result;
Put    @10, 'Rank', R,
        @10#2, 'Total Score', C.l,
        @10#3,  'Newscores'/;
        loop(i, put @1, i.tl, @5, G.l(i)/);
```

C.9 Model 3.1.1

```
$Title Model 3.1.1

Sets    j       countries /1*148/
        i       indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators “defined in Model 1.1” ;

Scalar T Total Budget /1000000/  ;

Parameters
U(i)    upper bound for Scores of country n /
1        100.0
2        100.0
3        100.0
4        100.0
5        100.0
6        100.0
7        100.0
8        100.0
9        100.0
10       100.0
11       100.0
12       100.0
13       100.0
14       100.0
15       100.0
16       100.0
17       100.0
18       100.0
19       100.0
20       100.0
21       100.0
22       100.0
23       100.0
24       100.0
25       100.0 /

L(i)    lower bound for Scores of country n /
1   85.96
2   93.21
3   94.59
4   88.42
5   76.73
6   99.99
7   93.61
8   99.95
9   53.97
10  84.66
11 100.00
12  10.81
13   2.82
14   0.00
15  11.00
16  34.37
17  62.50
18  96.82
19  77.56
20  42.12
```

21 87.49
22 86.36
23 95.67
24 50.43
25 53.32 /

W(i) weight i
/
1 0.0625
2 0.0625
3 0.25
4 0.05
5 0.05
6 0.025
7 0.0125
8 0.0125
9 0.0375
10 0.0375
11 0.025
12 0.0188
13 0.0188
14 0.0188
15 0.0188
16 0.0125
17 0.0125
18 0.005
19 0.005
20 0.005
21 0.005
22 0.005
23 0.0833
24 0.0833
25 0.0833 /

C(i) Cost of improvement in indicator i /
1 100000
2 50000
3 300
4 40000
5 8000
6 75000
7 10000
8 25000
9 15000
10 14000
11 25000
12 23000
13 1000
14 25000
15 23000
16 35000
17 70000
18 45000
19 47000
20 10000
21 35000
22 2000
23 18000
24 76000
25 2500 / ;

```
Variables
        G(i) score vector of country n
        B(i) budget vector for n
        z          result ;

Binary variable x(j) country rank calculator;

Equations
        Lower(i)        Lower bound for weight i
        Upper(i)        Upper bound for weight i
        Cost            Total cost of improvement
        Budget(i)       Budget allocated for indicator i
        Func            Objective function;

Lower(i)..              G(i)=g= L(i);
Upper(i)..              G(i)=l= U(i);
Cost..                  Sum(i,C(i)*G(i)) - Sum(i,C(i)*L(i)) =l= T;
Budget(i)..             C(i)*G(i) - C(i)*L(i) =e= B(i);
Func..                  Sum(i, w(i)*G(i))=e= z ;
Model Rashid /all/;
Option DNLP=CONOPT;

Solve Rashid using mip maximizing z ;

File result /D:\TEZ\Outputf\cikti.txt/;

Put result;
Put
        @10, 'Score', z.l,
        @10#2,  'Budget'/;
        loop(i, put @1, i.tl, @5, B.l(i)/);
        loop(i, put @1, i.tl, @5, G.l(i)/);
```

C.10 Model 3.1.2

```
$Title Model 3.1.2

Sets    j      countries /1*148/
        i      indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators "defined in Model 1.1" ;

Scalar
R country rank /40/
T Total Budget /1000000/  ;

Parameters
U(i)    upper bound for Scores of country n /
1       100.0
2       100.0
3       100.0
4       100.0
5       100.0
6       100.0
7       100.0
8       100.0
9       100.0
10      100.0
11      100.0
12      100.0
13      100.0
14      100.0
15      100.0
16      100.0
17      100.0
18      100.0
19      100.0
20      100.0
21      100.0
22      100.0
23      100.0
24      100.0
25      100.0/

L(i)    lower bound for Scores of country n /
1   85.96
2   93.21
3   94.59
4   88.42
5   76.73
6   99.99
7   93.61
8   99.95
9   53.97
10  84.66
11 100.00
12  10.81
13   2.82
14   0.00
15  11.00
16  34.37
17  62.50
18  96.82
```

19 77.56
20 42.12
21 87.49
22 86.36
23 95.67
24 50.43
25 53.32/

W(i)   weight i /
1   0.0625
2   0.0625
3   0.25
4   0.05
5   0.05
6   0.025
7   0.0125
8   0.0125
9   0.0375
10   0.0375
11   0.025
12   0.0188
13   0.0188
14   0.0188
15   0.0188
16   0.0125
17   0.0125
18   0.005
19   0.005
20   0.005
21   0.005
22   0.005
23   0.0833
24   0.0833
25   0.0833/

C(i)   Cost of improvement in indicator i /
1   100000
2   50000
3   300
4   40000
5   8000
6   75000
7   10000
8   25000
9   15000
10   14000
11   25000
12   23000
13   1000
14   25000
15   23000
16   35000
17   70000
18   45000
19   47000
20   10000
21   35000
22   2000
23   18000
24   76000

```
25       2500 / ;

Variables
        G(i) score vector of country n
        B(i) budget vector for n
        E    total score
        z    result ;

Binary variable x(j) country rank calculator;

Equations
        Rank           Determining final rank
        Large(j)       Finding larger score countries
        Terslarge(j)   Score condition
        Lower(i)       Lower bound for weight i
        Upper(i)       Upper bound for weight i
        Cost           Total cost of improvement
        Budget(i)      Budget allocated for indicator i
        Score          Total Score
        Func           Objective function ;
Rank..                 Sum(j, x(j)) + 1 =l= R;
Large(j)..             Sum(i, w(i)*S(j,i)) - Sum(i, w(i)*G(i)) =l= 100 * x(j);
Terslarge(j)..         Sum(i, w(i)*G(i)) - Sum(i, w(i)*S(j,i)) =l= 100 * (1-x(j));
Lower(i)..             G(i)=g= L(i);
Upper(i)..             G(i)=l= U(i);
Cost..                 Sum(i,C(i)*G(i)) - Sum(i,C(i)*L(i)) =e= T;
Budget(i)..            C(i)*G(i) - C(i)*L(i) =e= B(i);
Score..                Sum(i, w(i)*G(i)) =e= E ;
Func..                 z =e= 0 ;

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip minimizing z ;

File result /D:\TEZ\Outputf\cikti.txt/;

Put result;

Put
        @10, 'Rank', R,
        @10#2, 'Score', E.l,
        @10#3,  'Budget'/;
        loop(i, put @1, i.tl, @5, B.l(i)/);
        loop(i, put @1, i.tl, @5, G.l(i)/);
```

C.11 Model 3.2.1

```
$Title Model 3.2.1

Sets     j       countries /1*148/
         i       indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators “defined in Model 1.1” ;

Parameters
U(i)    upper bound for Scores of country n /
1        100.0
2        100.0
3        100.0
4        100.0
5        100.0
6        100.0
7        100.0
8        100.0
9        100.0
10       100.0
11       100.0
12       100.0
13       100.0
14       100.0
15       100.0
16       100.0
17       100.0
18       100.0
19       100.0
20       100.0
21       100.0
22       100.0
23       100.0
24       100.0
25       100.0 /
L(i)    lower bound for Scores of country n /
1   85.96
2   93.21
3   94.59
4   88.42
5   76.73
6   99.99
7   93.61
8   99.95
9   53.97
10  84.66
11 100.00
12  10.81
13   2.82
14   0.00
15  11.00
16  34.37
17  62.50
18  96.82
19  77.56
20  42.12
21  87.49
22  86.36
23  95.67
```

24 50.43
25 53.32 /
W(i)   weight i /
1   0.0625
2   0.0625
3   0.25
4   0.05
5   0.05
6   0.025
7   0.0125
8   0.0125
9   0.0375
10   0.0375
11   0.025
12   0.0188
13   0.0188
14   0.0188
15   0.0188
16   0.0125
17   0.0125
18   0.005
19   0.005
20   0.005
21   0.005
22   0.005
23   0.0833
24   0.0833
25   0.0833 /

C(i)   Cost of improvement in indicator i /
1   100000
2   50000
3   300
4   40000
5   8000
6   75000
7   10000
8   25000
9   15000
10   14000
11   25000
12   23000
13   1000
14   25000
15   23000
16   35000
17   70000
18   45000
19   47000
20   10000
21   35000
22   2000
23   18000
24   76000
25   2500 / ;

Variables
    G(i) score vector of country n
    B(i) budget vector for n
    T   Total budget

```
        z          result ;

Binary variable x(j) country rank calculator;

Equations
         Lower(i)       Lower bound for weight i
        Upper(i)       Upper bound for weight i
        Cost           Total cost of improvement
        Budget(i)      Budget allocated for indicator i
        Func           Objective function;

Lower(i)..             G(i)=g= L(i);
Upper(i)..             G(i)=l= U(i);
Cost..                 Sum(i,C(i)*G(i)) - Sum(i,C(i)*L(i)) =e= T;
Budget(i)..            C(i)*G(i) - C(i)*L(i) =e= B(i);
Func..                 Sum(i, w(i)*G(i)) =e= z ;

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip maximizing z ;

File result /D:\TEZ\Outputf\cikti.txt/;

Put result;

Put
        @10#1, 'Total Budget', T.l,
        @10#2,  'Budget'/;
        loop(i, put @1, i.tl, @5, B.l(i)/);
        loop(i, put @1, i.tl, @5, G.l(i)/);
```

C.12 Model 3.2.3

```
$Title Model 3.2.3

Sets    j       countries /1*148/
        i       indicators /1*25/   ;

Table  S(j,i) Scores of country for spesific indicators "defined in Model 1.1" ;

Scalar R country rank /40/

Parameters
U(i)    upper bound for Scores of country n /
1        100.0
2        100.0
3        100.0
4        100.0
5        100.0
6        100.0
7        100.0
8        100.0
9        100.0
10       100.0
11       100.0
12       100.0
13       100.0
14       100.0
15       100.0
16       100.0
17       100.0
18       100.0
19       100.0
20       100.0
21       100.0
22       100.0
23       100.0
24       100.0
25       100.0 /

L(i)    lower bound for Scores of country n /
1   85.96
2   93.21
3   94.59
4   88.42
5   76.73
6   99.99
7   93.61
8   99.95
9   53.97
10  84.66
11 100.00
12  10.81
13   2.82
14   0.00
15  11.00
16  34.37
17  62.50
18  96.82
19  77.56
20  42.12
```

```
21  87.49
22  86.36
23  95.67
24  50.43
25  53.32 /

W(i)    weight i /
1        0.0625
2        0.0625
3        0.25
4        0.05
5        0.05
6        0.025
7        0.0125
8        0.0125
9        0.0375
10       0.0375
11       0.025
12       0.0188
13       0.0188
14       0.0188
15       0.0188
16       0.0125
17       0.0125
18       0.005
19       0.005
20       0.005
21       0.005
22       0.005
23       0.0833
24       0.0833
25       0.0833 /

C(i)    Cost of improvement in indicator i /
1        100000
2        50000
3        300
4        40000
5        8000
6        75000
7        10000
8        25000
9        15000
10       14000
11       25000
12       23000
13       1000
14       25000
15       23000
16       35000
17       70000
18       45000
19       47000
20       10000
21       35000
22       2000
23       18000
24       76000
25       2500 / ;
```

```
Variables
         G(i) score vector of country n
         B(i) budget vector for n
         E    total score
         T    total budget
         z    result ;

Binary variable x(j) country rank calculator;

Equations

         Rank           Determining final rank
         Large(j)       Finding larger score countries
         Terslarge(j)   Score condition
         Lower(i)       Lower bound for weight i
         Upper(i)       Upper bound for weight i
         Cost           Total cost of improvement
         Budget(i)      Budget allocated for indicator i
         Score          Total Score
         Func           Objective function ;

Rank..              Sum(j, x(j)) + 1 =l= R;
Large(j)..          Sum(i, w(i)*S(j,i)) - Sum(i, w(i)*G(i)) =l= 100 * x(j);
Terslarge(j)..      Sum(i, w(i)*G(i)) - Sum(i, w(i)*S(j,i)) =l= 100 * (1-x(j));
Lower(i)..          G(i)=g= L(i);
Upper(i)..          G(i)=l= U(i);
Cost..              Sum(i,C(i)*G(i)) - Sum(i,C(i)*L(i)) =e= T;
Budget(i)..         C(i)*G(i) - C(i)*L(i) =e= B(i);
Score..             Sum(i, w(i)*G(i)) =e= E ;
Func..              z =e= T ;

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip minimizing z ;

File result /D:\TEZ\Outputf\cikti.txt/;

Put result;

Put
         @10, 'Rank', R,
         @10#2, 'Score', E.l,
         @10#3,'Total Budget', T.l,
         @10#5, 'Budget'/;
         loop(i, put @1, i.tl, @5, B.l(i)/);
         loop(i, put @1, i.tl, @5, G.l(i)/);
```

C.13 Model 4.1.1

```
$Title Model 4.1.1

Sets   j     countries /1*148/
       i     indicators /1*25/
       k     actions /1*7/ ;

Table  S(j,i) Scores of country for spesific indicators "defined in Model 1.1" ;

Table Y(k,i) Amount of improvement on indicator i with the action k
       1     2     3     4     5     6     7     8     9     10    11    12    13
14     15    16    17    18    19    20    21    22    23    24    25
1      1.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   3.0   0.0   0.0   0.0
0.0    0.0   0.0   0.0   0.0   2.0   5.0   6.0   0.0   3.0   0.0   0.0   0.0
2      5.0   4.0   1.0   0.0   0.0   0.0   0.0   0.0   8.0   4.0   0.0   1.0
2.0    1.0   3.0   4.0   0.0   1.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
3      0.0   0.0   2.0   4.0   5.0   0.0   2.0   0.0   0.0   0.0   0.0   2.0
0.0    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   2.0   7.0   8.0
4      0.0   0.0   1.0   2.0   2.0   0.0   1.0   0.0   0.0   0.0   0.0   0.0
2.0    2.0   0.0   0.0   0.0   0.0   0.0   0.0   5.0   0.0   0.0   1.0   1.0
5      0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   6.0
9.0    8.0   6.0   9.0   7.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
6      3.0   1.0   0.0   2.0   2.0   0.0   1.0   0.0   4.0   0.0   0.0   3.0
5.0    6.0   9.0   8.0   5.0   0.0   5.0   3.0   6.0   6.0   0.0   3.0   5.0
7      2.0   1.0   1.0   3.0   4.0   0.0   2.0   0.0   2.0   1.0   0.0   1.0
1.0    3.0   1.0   1.0   1.0   0.0   1.0   1.0   1.0   0.0   1.0   5.0   10.0
;

Scalar
T Total Budget /2500000/  ;

Parameters

U(i)   upper bound for Scores of country n /
1      100.0
2      100.0
3      100.0
4      100.0
5      100.0
6      100.0
7      100.0
8      100.0
9      100.0
10     100.0
11     100.0
12     100.0
13     100.0
14     100.0
15     100.0
16     100.0
17     100.0
18     100.0
19     100.0
20     100.0
21     100.0
22     100.0
23     100.0
24     100.0
25     100.0 /
```

L(i)   lower bound for Scores of country n /
1   85.96
2   93.21
3   94.59
4   88.42
5   76.73
6   99.99
7   93.61
8   99.95
9   53.97
10 84.66
11 100.00
12 10.81
13   2.82
14   0.00
15 11.00
16 34.37
17 62.50
18 96.82
19 77.56
20 42.12
21 87.49
22 86.36
23 95.67
24 50.43
25 53.32 /

W(i)   weight i /
1   0.0625
2   0.0625
3   0.25
4   0.05
5   0.05
6   0.025
7   0.0125
8   0.0125
9   0.0375
10   0.0375
11   0.025
12   0.0188
13   0.0188
14   0.0188
15   0.0188
16   0.0125
17   0.0125
18   0.005
19   0.005
20   0.005
21   0.005
22   0.005
23   0.0833
24   0.0833
25   0.0833 /

C(k)   Cost of action k /
1   200000.0
2   300000.0
3   400000.0
4   500000.0
5   600000.0

```
6       700000.0
7       800000.0 / ;

Variables
        G(i)      score vector of country n
        B         Budget used
        N         New total score of country n
        z         result ;

Binary variable
        F(k) action taking indicator ;

Equations

        Lower(i)      Lower bound for weight i
        Upper(i)      Upper bound for weight i
        Budget        Total budget constraint
        Score(i)      New score for country n for indicator i
        Nscore        New total score of country n
        Used          Budget used
        Actions       Action number
        Func          Objective function;

Lower(i)..          G(i)=g= L(i);
Upper(i)..          G(i)=l= U(i);
Budget..            Sum(k,C(k)*F(k))=l= T;
Score(i)..          L(i) + Sum(k,Y(k,i)*F(k)) =e= G(i) ;
Nscore..            Sum(i, w(i)*G(i))=e= N;
Used..              Sum(k,C(k)*F(k)) =e= B;
Actions..           Sum(k, F(k)) =l= 7 ;
Func..              z =e= Sum(i, w(i)*G(i)) ;

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip maximizing z ;

File result /D:\TEZ\Outputf\cikti.txt/;

Put result ;

Put
        @30, 'New Score', N.l ,
        @60, 'Budget Used', B.l ,
        @10#3,'Actions'/ ;
        loop(k, put @1, k.tl, @5, F.l(k)/);
```

C.14 Model 4.1.2

```
$Title Model 4.1.2

Sets    j       countries /1*148/
        i      indicators /1*25/
        k       actions /1*7/ ;

Table  S(j,i) Scores of country for spesific indicators “defined in Model 1.1” ;

Table Y(k,i) Amount of improvement on indicator i with the action k
        1       2       3       4       5       6       7       8       9       10      11      12      13
14      15      16      17      18      19      20      21      22      23      24      25
1       1.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     3.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     2.0     5.0     6.0     0.0     3.0     0.0     0.0     0.0
2       5.0     4.0     1.0     0.0     0.0     0.0     0.0     0.0     8.0     4.0     0.0     1.0
2.0     1.0     3.0     4.0     0.0     1.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
3       0.0     0.0     2.0     4.0     5.0     0.0     2.0     0.0     0.0     0.0     0.0     2.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     2.0     7.0     8.0
4       0.0     0.0     1.0     2.0     2.0     0.0     1.0     0.0     0.0     0.0     0.0     0.0
2.0     2.0     0.0     0.0     0.0     0.0     0.0     0.0     5.0     0.0     0.0     1.0     1.0
5       0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     6.0
9.0     8.0     6.0     9.0     7.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
6       3.0     1.0     0.0     2.0     2.0     0.0     1.0     0.0     4.0     0.0     0.0     3.0
5.0     6.0     9.0     8.0     5.0     0.0     5.0     3.0     6.0     6.0     0.0     3.0     5.0
7       2.0     1.0     1.0     3.0     4.0     0.0     2.0     0.0     2.0     1.0     0.0     1.0
1.0     3.0     1.0     1.0     1.0     0.0     1.0     1.0     1.0     0.0     1.0     5.0     10.0
;

Scalar
R Target Rank /40/;
*T Total Budget /2500000/  ;

Parameters

U(i)    upper bound for Scores of country n /
1       100.0
2       100.0
3       100.0
4       100.0
5       100.0
6       100.0
7       100.0
8       100.0
9       100.0
10      100.0
11      100.0
12      100.0
13      100.0
14      100.0
15      100.0
16      100.0
17      100.0
18      100.0
19      100.0
20      100.0
21      100.0
22      100.0
23      100.0
24      100.0
```

25 100.0 /

L(i) lower bound for Scores of country n /
1 85.96
2 93.21
3 94.59
4 88.42
5 76.73
6 99.99
7 93.61
8 99.95
9 53.97
10 84.66
11 100.00
12 10.81
13 2.82
14 0.00
15 11.00
16 34.37
17 62.50
18 96.82
19 77.56
20 42.12
21 87.49
22 86.36
23 95.67
24 50.43
25 53.32 /

W(i) weight i /
1 0.0625
2 0.0625
3 0.25
4 0.05
5 0.05
6 0.025
7 0.0125
8 0.0125
9 0.0375
10 0.0375
11 0.025
12 0.0188
13 0.0188
14 0.0188
15 0.0188
16 0.0125
17 0.0125
18 0.005
19 0.005
20 0.005
21 0.005
22 0.005
23 0.0833
24 0.0833
25 0.0833 /

C(k) Cost of action k /
1 200000.0
2 300000.0
3 400000.0

```
4       500000.0
5       600000.0
6       700000.0
7       800000.0 / ;

Variables
*R        ranking of the country
        G(i)      score vector of country n
        B         Budget used
        N         New total score of country n
        z         result ;

Binary variable
      x(j) country rank calculator
      F(k) action taking indicator ;

Equations
        Rank            Determining final rank
        Large(j)        Finding larger score countries
        Terslarge(j)    Score condition
        Lower(i)        Lower bound for weight i
        Upper(i)        Upper bound for weight i
        Score(i)        New score for country n for indicator i
        Nscore          New total score of country n
        Used            Budget used
        Actions         Action number
        Func            Objective function;

Rank..              Sum(j, x(j)) + 1 =l= R;
Large(j)..          Sum(i, w(i)*S(j,i)) - Sum(i, w(i)*G(i)) =l= 100 * x(j);
Terslarge(j)..      Sum(i, w(i)*G(i)) - Sum(i, w(i)*S(j,i)) =l= 100 * (1-x(j));
Lower(i)..          G(i)=g= L(i);
Upper(i)..          G(i)=l= U(i);
Score(i)..          L(i) + Sum(k,Y(k,i)*F(k)) =e= G(i) ;
Nscore..            Sum(i, w(i)*G(i))=e= N;
Used..              Sum(k,C(k)*F(k)) =e= B;
Actions..           Sum(k, F(k)) =l= 7 ;
Func..              z =e=  Sum(k,C(k)*F(k)) + 0.0067*Sum(j, x(j)) ;

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip minimizing z ;

File result /D:\TEZ\Outputf\cikti.txt/;

Put result ;

Put
        @10, 'Rank', z.l ,
        @30, 'New Score', N.l ,
        @60, 'Budget Used', B.l ,
        @10#3,'Actions'/ ;
        loop(k, put @1, k.tl, @5, F.l(k)/);
```

C.15 Model 4.2

```
$Title Model 4.2

Sets    j       countries /1*148/
        i       indicators /1*25/
        k       actions /1*7/ ;

Table  S(j,i) Scores of country for spesific indicators “defined in Model 1.1” ;

Table Y(k,i) Amount of improvement on indicator i with the action k
        1       2       3       4       5       6       7       8       9       10      11      12      13
14      15      16      17      18      19      20      21      22      23      24      25
1       1.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     3.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     2.0     5.0     6.0     0.0     3.0     0.0     0.0     0.0
2       5.0     4.0     1.0     0.0     0.0     0.0     0.0     0.0     8.0     4.0     0.0     1.0
2.0     1.0     3.0     4.0     0.0     1.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
3       0.0     0.0     2.0     4.0     5.0     0.0     2.0     0.0     0.0     0.0     0.0     2.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     2.0     7.0     8.0
4       0.0     0.0     1.0     2.0     2.0     0.0     1.0     0.0     0.0     0.0     0.0     0.0
2.0     2.0     0.0     0.0     0.0     0.0     0.0     0.0     5.0     0.0     0.0     1.0     1.0
5       0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     6.0
9.0     8.0     6.0     9.0     7.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
6       3.0     1.0     0.0     2.0     2.0     0.0     1.0     0.0     4.0     0.0     0.0     3.0
5.0     6.0     9.0     8.0     5.0     0.0     5.0     3.0     6.0     6.0     0.0     3.0     5.0
7       2.0     1.0     1.0     3.0     4.0     0.0     2.0     0.0     2.0     1.0     0.0     1.0
1.0     3.0     1.0     1.0     1.0     0.0     1.0     1.0     1.0     0.0     1.0     5.0     10.0
;

Scalar T Total Budget /2199999.0/  ;

Parameters

U(i)    upper bound for Scores of country n /
1       100.0
2       100.0
3       100.0
4       100.0
5       100.0
6       100.0
7       100.0
8       100.0
9       100.0
10      100.0
11      100.0
12      100.0
13      100.0
14      100.0
15      100.0
16      100.0
17      100.0
18      100.0
19      100.0
20      100.0
21      100.0
22      100.0
23      100.0
24      100.0
25      100.0  /
```

L(i)   lower bound for Scores of country n /
1   85.96
2   93.21
3   94.59
4   88.42
5   76.73
6   99.99
7   93.61
8   99.95
9   53.97
10 84.66
11 100.00
12 10.81
13   2.82
14   0.00
15 11.00
16 34.37
17 62.50
18 96.82
19 77.56
20 42.12
21 87.49
22 86.36
23 95.67
24 50.43
25 53.32 /

W(i)   weight i /
1   0.0625
2   0.0625
3   0.25
4   0.05
5   0.05
6   0.025
7   0.0125
8   0.0125
9   0.0375
10   0.0375
11   0.025
12   0.0188
13   0.0188
14   0.0188
15   0.0188
16   0.0125
17   0.0125
18   0.005
19   0.005
20   0.005
21   0.005
22   0.005
23   0.0833
24   0.0833
25   0.0833 /

C(k)   Cost of action k /
1   200000.0
2   300000.0
3   400000.0
4   500000.0
5   600000.0

```
6       700000.0
7       800000.0  / ;

Variables
        R         ranking of the country
        G(i)       score vector of country n
        B         Budget used
        N         New total score of country n
        z         result ;

Binary variable
      x(j) country rank calculator
      F(k) action taking indicator ;

Equations
        Rank          Determining final rank
        Large(j)       Finding larger score countries
        Terslarge(j)    Score condition
        Lower(i)       Lower bound for weight i
        Upper(i)       Upper bound for weight i
        Budget          Total budget constraint
        Score(i)       New score for country n for indicator i
        Nscore         New total score of country n
        Used          Budget used
        Actions        Action number
        Func          Objective function;

Rank..                  Sum(j, x(j)) + 1 =l= R;
Large(j)..              Sum(i, w(i)*S(j,i)) - Sum(i, w(i)*G(i)) =l= 100 * x(j);
Terslarge(j)..          Sum(i, w(i)*G(i)) - Sum(i, w(i)*S(j,i)) =l= 100 * (1-x(j));
Lower(i)..              G(i)=g= L(i);
Upper(i)..              G(i)=l= U(i);
Budget..                Sum(k,C(k)*F(k))=l= T;
Score(i)..              L(i) + Sum(k,Y(k,i)*F(k)) =e= G(i) ;
Nscore..                Sum(i, w(i)*G(i))=e= N;
Used..                  Sum(k,C(k)*F(k)) =e= B;
Actions..               Sum(k, F(k)) =l= 7 ;
Func..                  z =e=  Sum(j, x(j)) + 1 + 0.00000029*Sum(k,C(k)*F(k)) ;

Model Rashid /all/;

Option DNLP=CONOPT;

Solve Rashid using mip minimizing z ;

File result /D:\TEZ\Outputf\cikti.txt/;

Put result ;

Put
        @10, 'Rank', z.l ,
        @30, 'New Score', N.l ,
        @60, 'Budget Used', B.l ,
        @10#3,'Actions'/ ;
        loop(k, put @1, k.tl, @5, F.l(k)/);
```