Appendix A

In order to associate the CSD indicators with the vectors of the model we have used the process detailed in Figure A. In this process each indicator is associated with a four-dimensional vector

\[ I^\alpha = (\text{Environmental, Economic, Social, Institutional}) \]

that has values in the range \([0, 3]\). The association of the model and the CSD indicators was done by asking five experts to propose a value of affinity between each indicator on each one of the four dimensions of sustainability.

![Figure A. CSD indicators association.](image)

The result association was as show in the next table.

| CSD indicators | Model vectors | Expert association |
|----------------|---------------|--------------------|
| Two equal vectors | Mean | YES |
| One of the vectors is displaced in a random direction | List of indicators associated to vectors | NO |

These indicators are the core indicators that the Commission on Sustainable Development (CSD) has proposed in order to cover most of the issues that are relevant for sustainable development, these indicators provide critical information and are easily calculated. Even though all the CSD indicators were associated with one indicator from the model, the number of indicators in the model is higher than the CSD set. Not all vectors represent indicators of the CSD, but the vectors can be modified slightly so that most agents can be associated to specific indicators that will be built in the necessary case.

The association was used in the Scenarios section in order to exemplify the differences between scenarios and it was also used to propose the Paretian set for each scenario.

Appendix B

We represent specific scenarios through defining a specific \( J^0 \) matrix constructed by a questionnaire applied to stakeholders. The responses to this survey were used as indicated in Figure B.
|   | Sustainability indicators association part 1.                                      |
|---|----------------------------------------------------------------------------------|
| 10| Immunization against infectious childhood diseases                                 |
| 20| Gross intake into last year of primary education, by sex                          |
| 21| Suicide rate                                                                       |
| 30| Total fertility rate                                                                |
| 31| Prevalence of tobacco use                                                           |
| 32| Number of intentional homicides per 100,000 population                              |
| 33| Percent of population with access to primary health care facilities                 |
| 102| Share of imports from developing countries and from LDCs                          |
| 120| Number of internet users per 100 population                                         |
| 130| Contraceptive prevalence rate                                                       |
| 131| Share of women in wage employment in the non-agricultural sector                   |
| 133| Net enrollment rate in primary education                                            |
| 210| Domestic material consumption                                                       |
| 212| Investment share in GDP                                                             |
| 220| Assistance (ODA) given or received as a percentage of GNI                           |
| 221| Ratio of local residents to tourists in major tourist regions                       |
| 222| Human and economic loss due to natural disasters                                   |
| 230| Ratio of share in national income of highest to lowest quintile                     |
| 231| Adult literacy rate, by sex                                                         |
| 232| Gross savings                                                                      |
| 300| Current account deficit as percentage of GDP                                       |
| 310| Fixed telephone lines per 100 population                                            |
| 311| Dependency ratio                                                                   |
| 312| Debt to GNI ratio                                                                  |
| 313| Gross domestic product (GDP) per capita                                             |
| 320| Adjusted net savings                                                               |

The possible answers to the questionnaire were in the range of agreement from the values \(2, 1, 0, -1, -2\) corresponding to the Completely agree, Agree, No opinion, Disagree, Completely disagree. As there were four questions for the same \(J^0\) matrix, then the four questions where averaged. Finally, each question with all the participants answers was averaged.

- Current permanent crops and monocultures have a positive effect on the economy\(^1\) of the region you live in.
- Current use of fertilizers has a positive effect on the economy\(^1\) of the region you live in.
- Current availability of water (used in the economy\(^1\)) has a positive effect on the economy of the region you live in.
- Organic crops (crops that do not use synthetic products) have a positive effect on the economy\(^1\) of the region you live in.
- Current air quality has a positive effect on human well-being in the region you live in.
- Current water quality has a positive effect on human well-being in the region you live in.
- Current abundance of species has a positive effect on human well-being in the region you live in.
| Code | Description                                                                                                                                 |
|------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 321  | Gross domestic expenditure subscribers per 100 population                                                                                   |
| 322  | Share of households without electricity or other modern energy services                                                                    |
| 323  | Mortality rate under 5 years old                                                                                                            |
| 330  | Employment-population ratio, by sex                                                                                                          |
| 331  | Life long learning                                                                                                                           |
| 333  | Vulnerable employment                                                                                                                        |
| 1020 | Morbidity of major diseases such as HIV/AIDS, malaria, tuberculosis                                                                       |
| 1031 | Proportion of urban population living in slums                                                                                               |
| 1113 | Average tariff barriers imposed on exports from developing countries and LDCs                                                              |
| 1121 | Percentage of total population living in coastal areas                                                                                       |
| 1131 | Adult secondary (tertiary) schooling attainment level, by sex                                                                               |
| 1132 | Life expectancy at Birth                                                                                                                     |
| 1200 | Arable and permanent cropland area                                                                                                           |
| 1210 | FDI inflows and outflows as percentage of GNI                                                                                               |
| 1211 | Material intensity of the economy                                                                                                           |
| 1212 | Inflation                                                                                                                                  |
| 1220 | Percentage of population using solid fuels for cooking                                                                                       |
| 1221 | Annual energy consumption per capita, total and by main user category                                                                       |
| 1231 | Population growth rate                                                                                                                       |
| 1301 | Modal split of freight transport                                                                                                            |
| 1311 | Tourism contribution to GDP                                                                                                                  |
| 1320 | Mobile cellular telephone subscribers per 100 population                                                                                     |
| 1321 | Labor productivity and unit labor cost                                                                                                       |
| 1332 | Proportion of population below international poverty line                                                                                   |
| 1333 | Percent of population living below national poverty line                                                                                  |
| 2011 | Marine trophic index                                                                                                                         |
| 2031 | Proportion of population using an improved water source                                                                                      |
| 2032 | Proportion of population using improved sanitation facilities                                                                                |
| 2100 | Proportion of total water resources used                                                                                                     |
| 2102 | Proportion of marine area protected                                                                                                          |
| 2103 | Percent of forests damaged by defoliation                                                                                                   |
| 2113 | Proportion of terrestrial area protected, total and by ecological region                                                                   |

- Current abundance of green areas has a positive effect on human well-being in the region you live in.
- Normal fluctuating environmental conditions have a positive effect on the institutions[2] in the region you live in.
- Natural disasters have a positive effect on the institutions[2] in the region you live in.
- Current environmental laws have a positive effect on the reduction of air and water pollution in the region you live in.
- Current abundance of green areas has a positive effect on the institutions[1] in the region you live in.
- Current land use changes have a positive effect on the environment of the region you live in.
- Current industry in the region you live in has a positive effect on the air quality.
Table C. Sustainability indicators association part 3.

| Code | Description                                                                 |
|------|-----------------------------------------------------------------------------|
| 2122 | Fragmentation of habitat                                                   |
| 2131 | Bathing water quality                                                      |
| 2133 | Percentage of population having paid bribes                               |
| 2202 | Energy intensity of transport                                              |
| 2203 | Land use change                                                            |
| 2211 | Fertilizer use efficiency                                                 |
| 2212 | Generation of waste                                                       |
| 2221 | Modal split of passenger transportation                                    |
| 2222 | Percentage of population living in hazard prone areas                      |
| 2230 | Remittances as percentage of GNI                                           |
| 2233 | Use of agricultural pesticides                                            |
| 2250 | Area under organic farming                                                |
| 2310 | Percentage of population having paid bribes                               |
| 2313 | Share of renewable energy sources in total energy use                      |
| 2333 | Net Official Development                                                  |
| 3000 | Abundance of invasive alien species                                       |
| 3001 | Abundance of selected key species                                         |
| 3003 | Management effectiveness of protected areas                               |
| 3011 | Ambient concentration of air pollutants in urban areas                    |
| 3013 | Management of radioactive waste                                           |
| 3021 | Land affected by desertification                                          |
| 3022 | Proportion of fish stocks within safe biological limits                    |
| 3100 | Biochemical oxygen demand in water bodies                                 |
| 3101 | Area of coral reef ecosystems and percentage live cover                    |
| 3111 | Proportion of land area covered by forests                                |
| 3112 | Area of selected key ecosystems                                           |
| 3121 | Generation of hazardous waste                                              |
| 3122 | Presence of fecal coliform in freshwater                                   |
| 3202 | Water use intensity by economic activity                                  |
| 3211 | Waste treatment and disposal                                              |
| 3212 | Change in threat status of species                                        |
| 3213 | Consumption of ozone depleting substances                                 |
| 3221 | Land degradation                                                          |
| 3223 | Wastewater treatment                                                      |
| 3232 | Healthy life years expectancy                                              |
| 3233 | Nutritional status of children                                             |
| 3311 | Carbon dioxide emissions                                                  |
| 3321 | Emissions of greenhouse gases                                             |
| 3322 | Area under sustainable forest management                                   |

- Current industry in the region you live in has a positive effect on the water quality.
- Current industry in the region you live in has a positive effect on deforestation.
- Job security in the region you live in is becoming uncertain.
- Current availability of consumer products has a positive effect on the economy of households in the region you live in.
- Current availability of energy has a positive effect on the economy of households in the region you live in.
Sustainability questionnaire with N participants

Assign values in \([-2,2]\) to the answers,

\[i=0\]

\[i=i+1\]

Summation of answers from the ith participant and mean of the 4 answers corresponding and entry of J0

Mean of the N participants for each entry of J0

Mean values of the answers of the N participants

Figure B. Specific scenario creation.

- Current garbage recycling in households has a positive effect on the economy[1] in the region you live in.
- Current public and private spendings on education has a positive effect on the institutions[2] in the region you live in.
- Current labour productivity has a positive effect on the institutions[2] in the region you live in.
- Current public and private spendings on health has a positive effect on the institutions[2] in the region you live in.
- Current private and governmental funding and subsidies have a positive effect on the institutions[2] in the region you live in.
- Current commitment of citizens to recycling garbage has a positive effect on the environment in the region you live in.
- Current commitment of citizens to not pollute air and water has a positive effect on the environment in the region you live in.
- Current commitment of citizens to reduce water consumption has a positive effect on the environment in the region you live in.
- Current use of cars has a positive effect on the environment in the region you live in.
- Current amount of tourism has a positive effect on the economy[1] in the region you live in.
• Current amount of working hours has a positive effect on the economy[1] in the region you live in.

• The increase of working population has a positive effect on the economy[1] in the region you live in.

• Current labor efficiency has a positive effect on the economy[1] in the region you live in.

• Current corruption level has a positive effect on the institutions[2] in the region you live in.

• Current crime level has a positive effect on the institutions[2] in the region you live in.

• Current citizen implementation of the environmental laws has a positive effect on the institutions[2] in the region you live in.

• Current use of the social services by the citizens has a positive effect on the institutions[2] in the region you live in.

• Current engagement of institutions[2] in renewable energy issues has a positive effect on the environment in the region you live in.

• Current protection level of green areas has a positive effect on the environment in the region you live in.

• Current level of species protection has a positive effect on the environment in the region you live in.

• Current air and water pollution regulations have a positive effect on the environment in the region you live in.

• The promotion of tourism has a positive effect on the economy[1] in the region you live in.

• The promotion of sustainable economic practices has a positive effect on the economy[1] in the region you live in.

• The promotion of job creation has a positive effect on the economy[1] in the region you live in.

• Current business generation has a positive effect on the economy[1] in the region you live in.

• Job security has a positive effect on the society[3] in the region you live in.

• The promotion of culture has a positive effect on the society[3] in the region you live in.

• Current quality of the health services has a positive effect on the society[3] in the region you live in.

• Current quality of the education services has a positive effect on the society[3] in the region you live in.
[1] With the word 'economy' in the questionnaire, we mean the state of the region regarding the production and consumption of non-environmental and environmental goods and services together with the supply of money. It refers to both private and public organizations.

[2] With the word 'institutions' in the questionnaire, we mean organizations or other formal social structures that govern a field of action in the region we are analysing. These organizations may be governmental agencies, NGOs, universities, sports clubs, families, etc.; but also this dimension includes social norms, principles, rules and decision-making procedures. A positive effect on institutions can be for example an increased credibility, efficiency, security or empowerment.

[3] With 'society' we mean the population living together in the region we are analyzing. A positive effect on the society can be for example an increased cohesion, harmony and/or order.

This questionnaire was used with the methodology described in Scenario creation section in order to design the $J_0$ matrix and determine the scenario to be simulated.

Appendix C

Next we present the results of the statistical tests comparing the different scenarios. The test values on the three different tests consistently show lower values for the specific scenarios than for the random generated. For a 90% of confidence these values lead that the specific scenarios are statistically similar meanwhile the randomly generated scenarios are different.

Table D. $\chi^2$-square test of the Trondheim scenario for the degree distribution.

| Scenario 2.1 vs Scenario 2.2 | 1.0301 |
| Scenario 2.1 vs Scenario 2.3 | 1.0322 |
| Scenario 2.2 vs Scenario 2.3 | 1.0119 |

Table D shows the Chi-Square test using three different simulations for the same scenario. It shows that different simulations are statistically similar for the Trondheim specific scenario.

Table E. $\chi^2$-square test of the Jalisco scenario for the degree distribution.

| Scenario 3.1 vs Scenario 3.2 | 1.0128 |
| Scenario 3.1 vs Scenario 3.3 | 1.0981 |
| Scenario 3.2 vs Scenario 3.3 | 1.0121 |

Table E shows the Chi-Square test using three different simulations for the same scenario. It shows that different simulations are statistically similar for the Jalisco specific scenario.

Table F. $\chi^2$-square test of the random generated scenario number 2 for the degree distribution.

| Random 2.1 vs Random 2.2 | 13.56 |
| Random 2.1 vs Random 2.3 | 11.89 |
| Random 2.2 vs Random 2.3 | 13.08 |

Table F shows the Chi-Square test using three different simulations from a random generated scenario number 2. The result shows that the simulations are statistically different. Table G shows the Chi-Square test using three different simulations from the
Table G. $\chi$-square test of the random generated scenario number 3 for the degree distribution.

| Random 3.1 vs Random 3.2 | 16.51 |
|--------------------------|-------|
| Random 3.1 vs Random 3.3 | 13.23 |
| Random 3.2 vs Random 3.3 | 10.47 |

Table H. Student T-test of the Trondheim scenario for the clustering coefficient.

| Scenario 2.1 vs Scenario 2.2 | 3.825 |
|-----------------------------|-------|
| Scenario 2.1 vs Scenario 2.3 | 3.819 |
| Scenario 2.2 vs Scenario 2.3 | 4.0142 |

random generated scenario number 3. The result shows that the simulations are statistically different.

Table I shows the Student T-test using three different simulations from the Trondheim scenario. The result shows that the simulations are statistically similar.

Table I. Student T-test of the Jalisco scenario for the clustering coefficient.

| Scenario 3.1 vs Scenario 3.2 | 2.692 |
|-----------------------------|-------|
| Scenario 3.1 vs Scenario 3.3 | 3.0114 |
| Scenario 3.2 vs Scenario 3.3 | 3.0122 |

Table I shows the Student T-test using three different simulations from the Jalisco scenario. The result shows that the simulations are statistically similar.

Table J. Student T-test of the random generated scenario number 2.

| Random 2.1 vs Random 2.2 | 11.98 |
|--------------------------|-------|
| Random 2.1 vs Random 2.3 | 21.66 |
| Random 2.2 vs Random 2.3 | 35.49 |

Table J shows the Student T-test using three different simulations from the random generated scenario number 2. The result shows that the simulations are statistically different.

Table K. Student T-test of the random generated scenario number 3.

| Random 3.1 vs Random 3.2 | 103.22 |
|--------------------------|-------|
| Random 3.1 vs Random 3.3 | 75.46 |
| Random 3.2 vs Random 3.3 | 40.39 |

random generated scenario number 3. The result shows that the simulations are statistically different.

Table K shows the Student T-test using three different simulations from the random generated scenario number 3. The result shows that the simulations are statistically different.

Table L. Correlation of the scenario number 2.

| Scenario 2.1 vs Scenario 2.2 | 0.5021 |
|------------------------------|-------|
| Scenario 2.1 vs Scenario 2.3 | 0.585 |
| Scenario 2.2 vs Scenario 2.3 | 0.593 |

Table L shows the Pearson correlation coefficient using three different simulations from the Trondheim scenario. The result shows that the simulations have a correlation.

Table M shows the Pearson correlation coefficient using three different simulations from the Jalisco scenario. The result shows that the simulations have a correlation.
Table M. Correlation of the scenario number 3.

| Scenario 3.1 vs Scenario 3.2 | 0.391 |
| Scenario 3.1 vs Scenario 3.3 | 0.386 |
| Scenario 3.2 vs Scenario 3.3 | 0.389 |

Table N. Student T-test of the random generated scenario number 2.

| Random 2.1 vs Random 2.2 | 0.00401 |
| Random 2.1 vs Random 2.3 | 0.0178  |
| Random 2.2 vs Random 2.3 | 0.00262 |

Table N shows the Pearson correlation coefficient using three different simulations from the random generated scenario number 2. The result shows that the simulations have no correlation.

Table O. Student T-test of the random generated scenario number 3.

| Random 3.1 vs Random 3.2 | 0.8406 |
| Random 3.1 vs Random 3.3 | 0.3039 |
| Random 3.2 vs Random 3.3 | 0.4250 |

Table O shows the Pearson correlation coefficient using three different simulations from the random generated scenario number 3. The result shows that the simulations have no correlation.

These results show differences between simulations from different specific scenarios (SS) and random generated scenarios (RGS). The SS simulations showed to be statistically similar between them and RGS simulations does not. The results were used in the Stability of simulations section.

Appendix D

The random generated scenarios are built by assigning uniform random float number in the range [-2,-2] to the J0 matrix of Eq(1), following by the same procedure of creating the interaction matrix J as in Eq(2).