

# Supplementary Material

Uncovering Synergies and Trade-offs in SDG Indicators via Explainable Machine Learning on Network Structures

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Table S1: Categorisation of countries based on SDG Index scores.

<b>Worst-performing countries (SDG Index &lt; 50)</b>
Afghanistan, Central African Republic, Chad, Democratic Republic of the Congo, Somalia, South Sudan, Sudan, Yemen
<b>Moderate-performing countries (50 ≤ SDG Index &lt; 80)</b>
Albania, Algeria, Angola, Argentina, Armenia, Australia, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darassalam, Bulgaria, Burkina Faso, Burundi, Cabo Verde, Cambodia, Cameroon, Canada, Chile, China, Colombia, Comoros, Costa Rica, Côte d'Ivoire, Cuba, Cyprus, Djibouti, Dominican Republic, Ecuador, Egypt, El Salvador, Eswatini, Ethiopia, Fiji, Gabon, Gambia, Georgia, Ghana, Greece, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, India, Indonesia, Iran, Iraq, Ireland, Israel, Jamaica, Jordan, Kazakhstan, Kenya, Korea Republic, Kuwait, Kyrgyz Republic, Lao PDR, Lebanon, Lesotho, Liberia, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nepal, New Zealand, Nicaragua, Niger, Nigeria, North Macedonia, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Qatar, Republic of the Congo, Romania, Russian Federation, Rwanda, São Tomé and Príncipe, Saudi Arabia, Senegal, Serbia, Sierra Leone, Singapore, South Africa, Sri Lanka, Suriname, Switzerland, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Türkiye, Turkmenistan, Uganda, Ukraine, United Arab Emirates, United States, Uruguay, Uzbekistan, Venezuela, Vietnam, Zambia, Zimbabwe
<b>Best-performing countries (SDG Index ≥ 80)</b>
Austria, Belgium, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Italy, Japan, Latvia, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom

Table S2: List of SDG Indicators for India

No.	SDG	Indicator Description
1	SDG 1	Poverty headcount ratio at \$2.15/day (2017 PPP, %)
2	SDG 1	Poverty headcount ratio at \$3.65/day (2017 PPP, %)
3	SDG 2	Prevalence of undernourishment (%)
4	SDG 2	Prevalence of stunting in children under 5 years of age (%)
5	SDG 2	Prevalence of wasting in children under 5 years of age (%)

No.	SDG	Indicator Description
6	SDG 2	Prevalence of obesity, BMI $\geq$ 30 (% of adult population)
7	SDG 2	Human Trophic Level (best 2-3 worst)
8	SDG 2	Cereal yield (tonnes per hectare of harvested land)
9	SDG 2	Sustainable Nitrogen Management Index (best 0-1.41 worst)
10	SDG 3	Maternal mortality rate (per 100,000 live births)
11	SDG 3	Neonatal mortality rate (per 1,000 live births)
12	SDG 3	Mortality rate, under-5 (per 1,000 live births)
13	SDG 3	Incidence of tuberculosis (per 100,000 population)
14	SDG 3	Age-standardized death rate due to cardiovascular disease, cancer, diabetes, or chronic respiratory disease in adults aged 30–70 years (%)
15	SDG 3	Traffic deaths (per 100,000 population)
16	SDG 3	Life expectancy at birth (years)
17	SDG 3	Adolescent fertility rate (births per 1,000 females aged 15 to 19)
18	SDG 3	Births attended by skilled health personnel (%)
19	SDG 3	Surviving infants who received 2 WHO-recommended vaccines (%)
20	SDG 3	Universal health coverage (UHC) index of service coverage (worst 0-100 best)
21	SDG 3	Subjective well-being (average ladder score, worst 0-10 best)
22	SDG 4	Participation rate in pre-primary organized learning (% of children aged 4 to 6)
23	SDG 4	Net primary enrollment rate (%)
24	SDG 4	Lower secondary completion rate (%)
25	SDG 4	Literacy rate (% of population aged 15 to 24)
26	SDG 5	Demand for family planning satisfied by modern methods (% of females aged 15 to 49)
27	SDG 5	Ratio of female-to-male mean years of education received (%)
28	SDG 5	Ratio of female-to-male labor force participation rate (%)
29	SDG 5	Seats held by women in national parliament (%)
30	SDG 6	Population using at least basic drinking water services (%)
31	SDG 6	Population using at least basic sanitation services (%)
32	SDG 6	Freshwater withdrawal (% of available freshwater resources)
33	SDG 6	Scarce water consumption embodied in imports ( $m^3H_2O$ eq/capita)
34	SDG 7	Population with access to electricity (%)
35	SDG 7	Population with access to clean fuels and technology for cooking (%)
36	SDG 7	$CO_2$ emissions from fuel combustion per total electricity output ( $MtCO_2/TWh$ )
37	SDG 7	Renewable energy share in total final energy consumption (%)
38	SDG 8	Adults with an account at a bank or other financial institution or with a mobile-money-service provider (% of population aged 15 or over)
39	SDG 8	Unemployment rate (% of total labor force, ages 15+)
40	SDG 8	Fundamental labor rights are effectively guaranteed (worst 0–1 best)
41	SDG 8	Fatal work-related accidents embodied in imports (per million population)
42	SDG 9	Rural population with access to all-season roads (%)
43	SDG 9	Population using the internet (%)

No.	SDG	Indicator Description
44	SDG 9	Mobile broadband subscriptions (per 100 population)
45	SDG 9	Logistics Performance Index: Infrastructure Score (worst 1–5 best)
46	SDG 9	The Times Higher Education Universities Ranking: Average score of top 3 universities (worst 0-100 best)
47	SDG 9	Articles published in academic journals (per 1,000 population)
48	SDG 9	Expenditure on research and development (% of GDP)
49	SDG 9	Total patent applications by applicant's origin (per million population)
50	SDG 10	Gini coefficient
51	SDG 10	Palma ratio
52	SDG 11	Proportion of urban population living in slums (%)
53	SDG 11	Annual mean concentration of PM2.5 ( $\mu g/m^3$ )
54	SDG 11	Access to improved water source, piped (% of urban population)
55	SDG 12	Production-based air pollution (DALYs per 1,000 population)
56	SDG 12	Air pollution associated with imports (DALYs per 1,000 population)
57	SDG 12	Production-based nitrogen emissions (kg/capita)
58	SDG 12	Nitrogen emissions associated with imports (kg/capita)
59	SDG 13	$CO_2$ emissions from fossil fuel combustion and cement production (t $CO_2$ /capita)
60	SDG 13	GHG emissions embodied in imports (t $CO_2$ /capita)
61	SDG 14	Ocean Health Index: Clean Waters score (worst 0-100 best)
62	SDG 14	Fish caught from overexploited or collapsed stocks (% of total catch)
63	SDG 14	Fish caught by trawling or dredging (%)
64	SDG 14	Fish caught that are then discarded (%)
65	SDG 15	Mean area that is protected in terrestrial sites important to biodiversity (%)
66	SDG 15	Mean area that is protected in freshwater sites important to biodiversity (%)
67	SDG 15	Red List Index of species survival (worst 0-1 best)
68	SDG 15	Permanent deforestation (% of forest area, 3-year average)
69	SDG 15	Imported deforestation ( $m^2$ /capita)
70	SDG 16	Homicides (per 100,000 population)
71	SDG 16	Crime is effectively controlled
72	SDG 16	Unsentenced detainees (% of prison population)
73	SDG 16	Corruption Perceptions Index (worst 0-100 best)
74	SDG 16	Press Freedom Index (worst 0-100 best)
75	SDG 16	Access to and affordability of justice (worst 0–1 best)
76	SDG 16	Timeliness of administrative proceedings (worst 0 - 1 best)
77	SDG 16	Expropriations are lawful and adequately compensated (worst 0 - 1 best)
78	SDG 17	Government spending on health and education (% of GDP)
79	SDG 17	Other countries: Government revenue excluding grants (% of GDP)
80	SDG 17	Statistical Performance Index (worst 0-100 best)

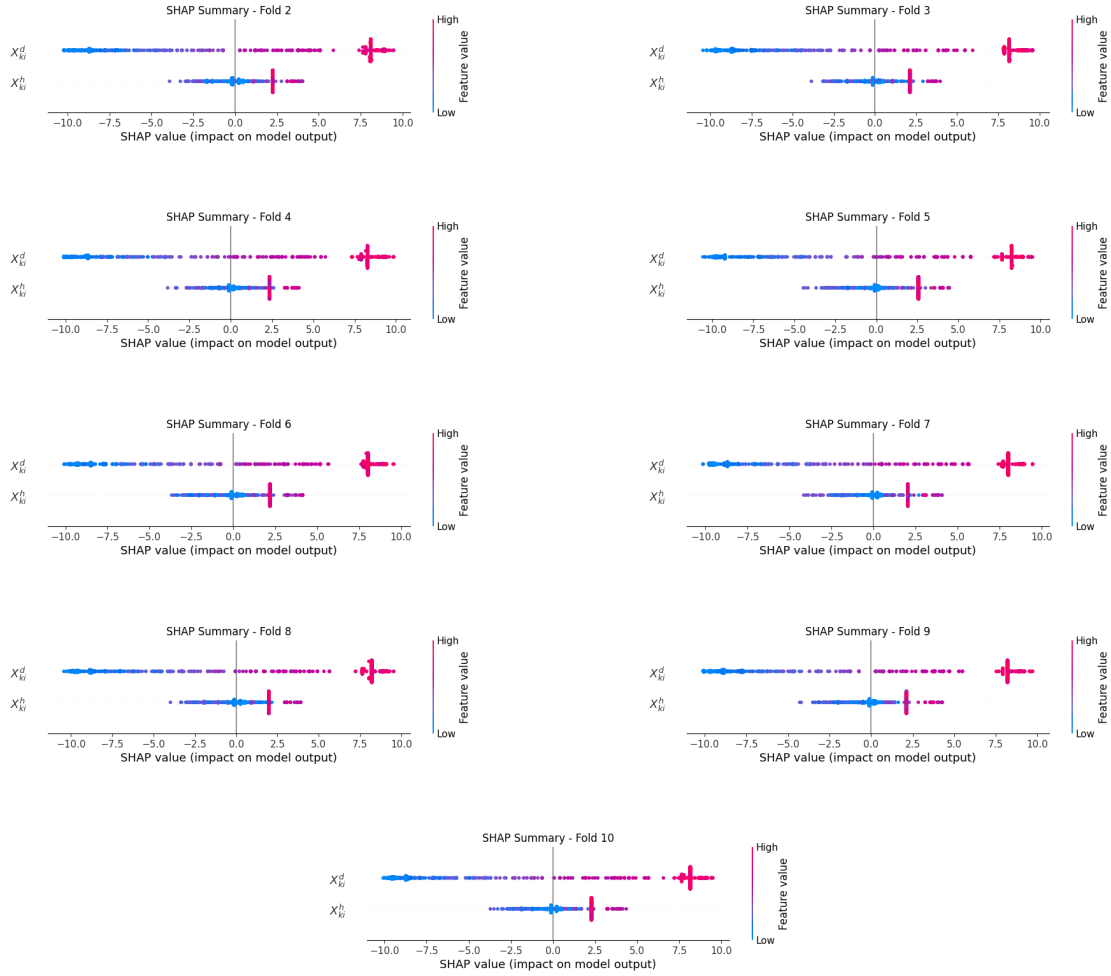


Figure S1: SHAP summary plot for the XGBoost model (fold 2 to fold 10) illustrating the contribution of direct ( $X_{ki}^d$ ) and indirect ( $X_{ki}^h$ ) network effects to the prediction of synergy dominance. Each point represents an indicator observation, with colour indicating feature value (red: high, blue: low) and horizontal position representing the impact on model output.

Table S3: List of SDG Indicators for Italy

No.	SDG	Indicator Description
1	SDG 1	Poverty headcount ratio at \$2.15/day (%)
2	SDG 1	Poverty headcount ratio at \$3.65/day (%)
3	SDG 2	Prevalence of obesity, BMI $\geq 30$ (% of adult population)
4	SDG 2	Human Trophic Level (best 2–3 worst)
5	SDG 2	Cereal yield (tonnes per hectare of harvested land)
6	SDG 2	Sustainable Nitrogen Management Index (best 0–1.41 worst)
7	SDG 3	Maternal mortality ratio (per 100,000 live births)
8	SDG 3	Neonatal mortality rate (per 1,000 live births)
9	SDG 3	Mortality rate, under-5 (per 1,000 live births)
10	SDG 3	Incidence of tuberculosis (per 100,000 population)
11	SDG 3	New HIV infections (per 1,000 uninfected population, all ages)

No.	SDG	Indicator Description
12	SDG 3	Age-standardized death rate due to cardiovascular disease, cancer, diabetes, or chronic respiratory disease in adults aged 30–70 years (%)
13	SDG 3	Traffic deaths (per 100,000 population)
14	SDG 3	Life expectancy at birth (years)
15	SDG 3	Adolescent fertility rate (births per 1,000 females aged 15–19)
16	SDG 3	Births attended by skilled health personnel (%)
17	SDG 3	Surviving infants who received 2 WHO-recommended vaccines (%)
18	SDG 3	Universal health coverage (UHC) index of service coverage (worst 0–100 best)
19	SDG 3	Subjective well-being (average ladder score, worst 0–10 best)
20	SDG 4	Participation rate in pre-primary organized learning (% of children aged 4 to 6)
21	SDG 4	Net primary enrollment rate (%)
22	SDG 4	Lower secondary completion rate (%)
23	SDG 5	Demand for family planning satisfied by modern methods (% of females aged 15–49)
24	SDG 5	Ratio of female-to-male mean years of education received (%)
25	SDG 5	Ratio of female-to-male labor force participation rate (%)
26	SDG 5	Seats held by women in national parliament (%)
27	SDG 6	Population using at least basic drinking water services (%)
28	SDG 6	Population using at least basic sanitation services (%)
29	SDG 6	Freshwater withdrawal (% of available freshwater resources)
30	SDG 6	Anthropogenic wastewater that receives treatment (%)
31	SDG 6	Scarce water consumption embodied in imports ( $m^3H_2O$ eq/capita)
32	SDG 7	$CO_2$ emissions from fuel combustion per total electricity output ( $MtCO_2/TWh$ )
33	SDG 7	Renewable energy share in total final energy consumption (%)
34	SDG 8	Adults with an account at a bank or other financial institution or with a mobile-money-service provider (% of population aged 15 or over)
35	SDG 8	Unemployment rate (% of total labor force, ages 15+)
36	SDG 8	Fundamental labor rights are effectively guaranteed (worst 0–1 best)
37	SDG 8	Fatal work-related accidents embodied in imports (per million population)
38	SDG 9	Population using the internet (%)
39	SDG 9	Mobile broadband subscriptions (per 100 population)
40	SDG 9	Logistics Performance Index: Infrastructure Score (worst 1–5 best)
41	SDG 9	Articles published in academic journals (per 1,000 population)
42	SDG 9	Expenditure on research and development (% of GDP)
43	SDG 9	Total patent applications by applicant's origin (per million population)
44	SDG 10	Gini coefficient
45	SDG 10	Palma ratio
46	SDG 11	Annual mean concentration of PM2.5 ( $\mu g/m^3$ )
47	SDG 12	Production-based air pollution (DALYs per 1,000 population)
48	SDG 12	Air pollution associated with imports (DALYs per 1,000 population)

No.	SDG	Indicator Description
49	SDG 12	Production-based nitrogen emissions (kg/capita)
50	SDG 12	Nitrogen emissions associated with imports (kg/capita)
51	SDG 12	Exports of plastic waste (kg/capita)
52	SDG 13	$CO_2$ emissions from fossil fuel combustion and cement production ( $tCO_2$ /capita)
53	SDG 13	GHG emissions embodied in imports ( $tCO_2$ /capita)
54	SDG 14	Mean area that is protected in marine sites important to biodiversity (%)
55	SDG 14	Ocean Health Index: Clean Waters score (worst 0–100 best)
56	SDG 14	Fish caught from overexploited or collapsed stocks (% of total catch)
57	SDG 14	Fish caught by trawling or dredging (%)
58	SDG 14	Fish caught that are then discarded (%)
59	SDG 15	Mean area that is protected in terrestrial sites important to biodiversity (%)
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61	SDG 15	Red List Index of species survival (worst 0–1 best)
62	SDG 15	Permanent deforestation (% of forest area, 3-year average)
63	SDG 15	Imported deforestation ( $m^2$ /capita)
64	SDG 16	Homicides (per 100,000 population)
65	SDG 16	Crime is effectively controlled (worst 0–1 best)
66	SDG 16	Unsentenced detainees (% of prison population)
67	SDG 16	Corruption Perceptions Index (worst 0–100 best)
68	SDG 16	Press Freedom Index (worst 0–100 best)
69	SDG 16	Access to and affordability of justice (worst 0–1 best)
70	SDG 16	Timeliness of administrative proceedings (worst 0–1 best)
71	SDG 16	Expropriations are lawful and adequately compensated (worst 0–1 best)
72	SDG 17	Government spending on health and education (% of GDP)
73	SDG 17	International concessional public finance, including official development assistance (% of GNI)
74	SDG 17	Corporate Tax Haven Score (best 0–100 worst)
75	SDG 17	Statistical Performance Index (worst 0–100 best)