**CO2 Emissions Cluster Profiles Report**

**Project Overview**

This report documents the cluster profiles identified in the CO2 emissions clustering analysis. Using a comprehensive dataset with indicators of emissions intensity, energy mix, and historical context, countries were grouped based on similar emissions characteristics using hierarchical clustering.

**Methodology**

* **Data**: Global CO2 emissions dataset with 79 variables (2019 data)
* **Clustering Features**: CO2 per capita, energy source mix (coal, oil, gas shares), cumulative CO2 emissions
* **Dimensionality Reduction**: Principal Component Analysis (PCA) for visualization
* **Clustering Method**: Hierarchical clustering with Ward's linkage

**5-Cluster Solution**

The primary analysis identified five distinct emissions profiles:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Cluster** | **Size** | **CO2 Per Capita** | **Coal Share** | **Oil Share** | **Gas Share** | **Cumulative CO2** | **Label** |
| 0 | 89 | 3.53 | 0.14 | 0.55 | 0.31 | 4,066.53 | Moderate Mixed-Source Emitters |
| 1 | 92 | 2.88 | 0.02 | 0.98 | 0.01 | 127.79 | Oil-Dependent Low-Impact Economies |
| 2 | 34 | 6.82 | 0.59 | 0.29 | 0.12 | 24,310.22 | Coal-Dependent Heavy Emitters |
| 3 | 1 | 15.73 | 0.21 | 0.46 | 0.33 | 412,183.81 | Exceptional Emitter: Unique Emissions Profile |
| 4 | 12 | 20.52 | 0.02 | 0.38 | 0.60 | 5,630.68 | Gas-Dominant High Per-Capita Emitters |

**Cluster Descriptions**

**Cluster 0: Moderate Mixed-Source Emitters (89 countries)**

* Medium emissions intensity with a balanced energy portfolio
* Oil forms the largest share but with significant gas and coal components
* Modest historical emissions contribution
* Likely includes many middle-income and smaller developed countries

**Cluster 1: Oil-Dependent Low-Impact Economies (92 countries)**

* Lower-middle emissions per capita
* Nearly exclusive reliance on oil (98%)
* Very low historical emissions
* Likely includes many developing nations with oil-based transportation and power sectors

**Cluster 2: Coal-Dependent Heavy Emitters (34 countries)**

* High per-capita emissions
* Coal dominates the energy mix (59%)
* Substantial historical emissions
* Likely includes coal-reliant industrializing economies and major coal exporters

**Cluster 3: Exceptional Emitter: Unique Emissions Profile (1 country - USA)**

* Extremely high per-capita emissions
* Balanced energy mix across all fossil fuels
* Extraordinary cumulative emissions
* Stands entirely alone in emissions characteristics

**Cluster 4: Gas-Dominant High Per-Capita Emitters (12 countries)**

* Highest per-capita emissions across all clusters
* Natural gas forms the majority of emissions (60%)
* Moderate historical emissions footprint
* Likely includes oil and gas-producing nations with energy-intensive economies

**8-Cluster Solution**

The advanced analysis revealed more nuanced groupings:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Cluster** | **Size** | **CO2 Per Capita** | **Coal Share** | **Oil Share** | **Gas Share** | **Cumulative CO2** | **Label** |
| 0 | 74 | 3.53 | 0.17 | 0.60 | 0.23 | 4,019.88 | Moderate Mixed-Source Emitters |
| 1 | 12 | 20.52 | 0.02 | 0.38 | 0.60 | 5,630.68 | Gas-Dominant High Per-Capita Emitters |
| 2 | 29 | 6.55 | 0.63 | 0.29 | 0.09 | 8,656.62 | Coal-Dependent Industrializing Economies |
| 3 | 11 | 10.88 | 0.02 | 0.98 | 0.00 | 89.00 | Ultra Oil-Dependent Nations |
| 4 | 5 | 8.38 | 0.37 | 0.33 | 0.30 | 115,101.12 | Major Historical Emitters |
| 5 | 15 | 3.54 | 0.04 | 0.34 | 0.62 | 4,253.11 | Gas-Focused Moderate Emitters |
| 6 | 81 | 1.80 | 0.01 | 0.98 | 0.01 | 133.06 | Low-Emission Oil-Dependent Economies |
| 7 | 1 | 15.73 | 0.21 | 0.46 | 0.33 | 412,183.81 | Exceptional Emitter: Unique Emissions Profile |

**Advanced Cluster Descriptions**

**Cluster 0: Moderate Mixed-Source Emitters (74 countries)**

* Medium emissions intensity with oil dominance
* Better balanced energy mix than in 5-cluster solution
* Moderate historical emissions
* Represents the "middle of the road" emissions profile globally

**Cluster 1: Gas-Dominant High Per-Capita Emitters (12 countries)**

* Identical to Cluster 4 in 5-cluster solution
* Very high per-capita emissions
* Natural gas dominance with significant oil contribution
* Likely includes Gulf states and other gas-rich economies

**Cluster 2: Coal-Dependent Industrializing Economies (29 countries)**

* High per-capita emissions
* Heavily coal-dependent (63%)
* Substantial but not extreme historical emissions
* Likely includes rapidly industrializing nations relying on coal power

**Cluster 3: Ultra Oil-Dependent Nations (11 countries)**

* Very high per-capita emissions
* Nearly exclusive oil dependence (98%)
* Surprisingly low cumulative emissions
* Likely includes oil-rich nations with smaller populations

**Cluster 4: Major Historical Emitters (5 countries)**

* High per-capita emissions
* Balanced energy mix across all fossil fuel sources
* Extremely high cumulative emissions
* Likely includes China, Russia, and other industrial powers with long emissions histories

**Cluster 5: Gas-Focused Moderate Emitters (15 countries)**

* Moderate per-capita emissions
* Gas-dominated energy mix (62%)
* Moderate historical impact
* Likely includes nations with significant natural gas resources

**Cluster 6: Low-Emission Oil-Dependent Economies (81 countries)**

* Low per-capita emissions
* Almost exclusive oil dependence (98%)
* Minimal historical emissions
* Likely represents many developing nations, particularly in Africa and parts of Asia

**Cluster 7: Exceptional Emitter: Unique Emissions Profile (1 country - USA)**

* Same as Cluster 3 in 5-cluster solution
* Extraordinarily high cumulative emissions separate it from all other countries
* Balanced fossil fuel mix
* Represents a unique emissions profile unlike any other nation

**Units of Measurement**

* **CO2 per capita**: Metric tons of CO2 per person per year
* **Coal/oil/gas share**: Proportion of emissions from each source (decimal, sum to 1.0)
* **Cumulative CO2**: Million metric tons of historical CO2 emissions

**Key Insights**

1. The United States stands alone as an exceptional emitter with unmatched historical emissions
2. High per-capita emitters fall into distinct categories based on their dominant energy source
3. Oil-dependent economies show wide variation in per-capita emissions
4. Major historical emitters typically have more balanced energy portfolios
5. Coal dependence correlates strongly with higher emissions intensity

These distinct emissions profiles provide a foundation for targeted climate policy approaches based on countries' specific emissions characteristics rather than one-size-fits-all strategies.