# Sustainable Development Through Wavelet-Quantile Analysis

Examining how GDP, population, green technologies, renewable energy, and labor productivity shape environmental sustainability across four developed nations

Natalia Veselitskaya, HSE University, Russia

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https://onlinelibrary.wiley.com/action/doSearch?ContribRaw=Veselitskaya%2C+Natalia&SeriesKey=10991719

# The Challenge: Balancing Growth and Environment

## The Core Question

How do economic growth, technology, and population affect environmental capacity in developed economies?

## The Measure

Load Capacity Factor (LCF) reveals the ratio of biocapacity* to ecological footprint**—a key sustainability indicator.

## The Gap

Limited research examines how green patents, renewable energy, and productivity interact with LCF over time and frequency.

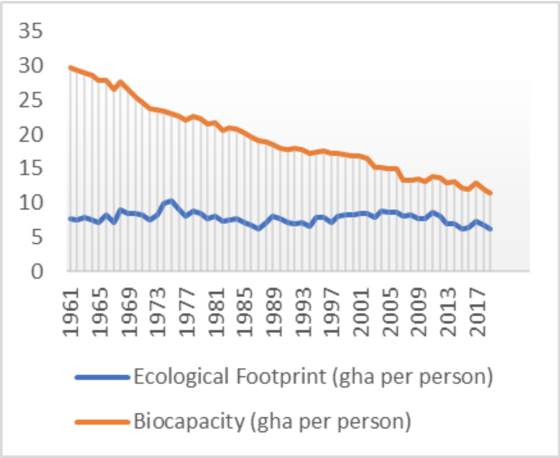
*Biocapacity is the capacity of ecosystems to regenerate resources and absorb waste, essentially measuring nature's ability to supply renewable resources and absorb waste.
**Ecological Footprint measures how fast we consume resources and generate waste compared to how fast nature can absorb our waste and generate resources

# Four Countries, Two Environmental Profiles (1)

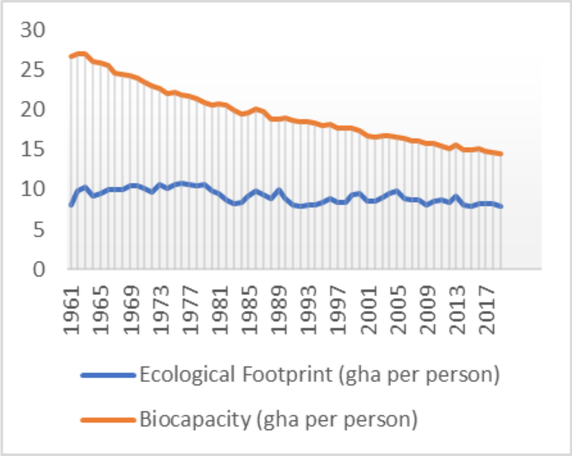
## Above Sustainability Limit

**Australia & Canada:** higher biocapacity than ecological footprint. Resource-exporting economies with large landmasses, low population density, and significant renewable energy potential.

Australia




Canada




Ecological Footprint and Biocapacity (gha per person)

**Source of data:** [https://data.footprintnetwork.org/](https://data.footprintnetwork.org/)

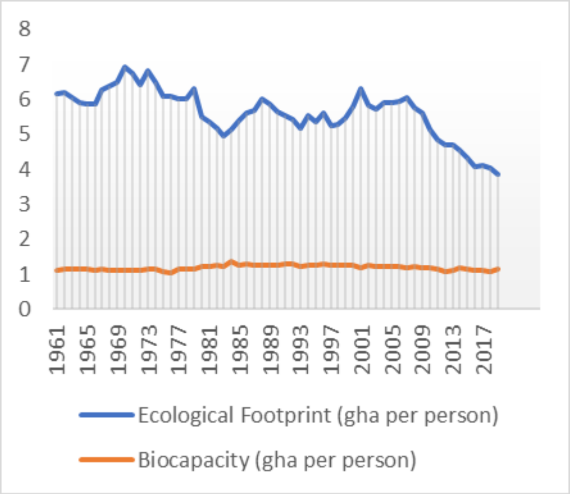
"GHA per person" refers to global hectares (gha) per person, a unit used to measure an individual's ecological footprint, which is the demand on nature for resources like food, fiber, and space for infrastructure, as well as the ability of ecosystems to absorb waste. Globally, the average ecological footprint is approximately 2.8 gha per person, but the Earth's biocapacity is only 1.6 gha per person, indicating humanity is using resources faster than they can be regenerated.

# Four Countries, Two Environmental Profiles (2)

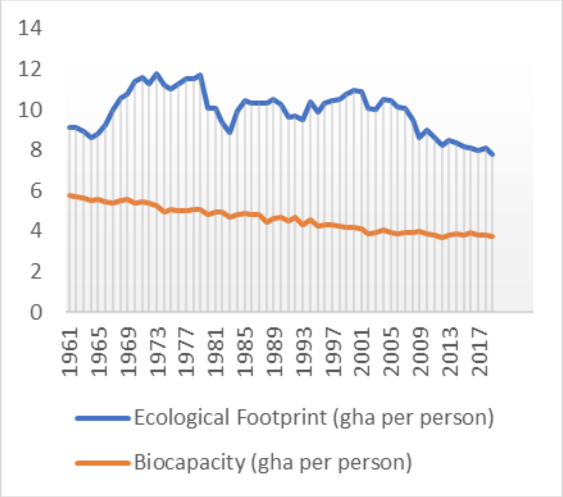
Below sustainability limit

**UK & USA:** Lower biocapacity than ecological footprint. Industrialized, post-industrial economies with high population density and greater resource dependence.

UK




USA




Ecological Footprint and Biocapacity (gha per person)

**Source of data:** https://data.footprintnetwork.org/

# Five Key Factors influencing the Environmental Quality

1

## GDP

Economic growth increases consumption and industrial activity, pressuring natural resources and energy systems.

2

## Population

Growing populations demand more energy, infrastructure, and resources, straining environmental capacity.

3

## Green Patents

Environmental technology patents drive innovation in energy efficiency and carbon reduction.

4

## Renewable Energy Usage

Transitioning from fossil fuels reduces carbon-intensive production and improves environmental footprint.

5

## Labor Productivity

Efficiency gains can reduce waste and energy use—or accelerate production and consumption.

# Methodology: Advanced Time-Frequency Analysis

This study employs two sophisticated analytical approaches to capture complex, nonlinear relationships across time and frequency domains:

1

### Wavelet Coherence Analysis (WCA)

Identifies time-varying correlations and causal relationships between variables at different frequencies, revealing short-term and long-term dynamics.

2

### Wavelet Quantile Regression (WQR)

Examines how variable relationships differ across quantile levels and time scales, capturing heterogeneous effects across environmental conditions.

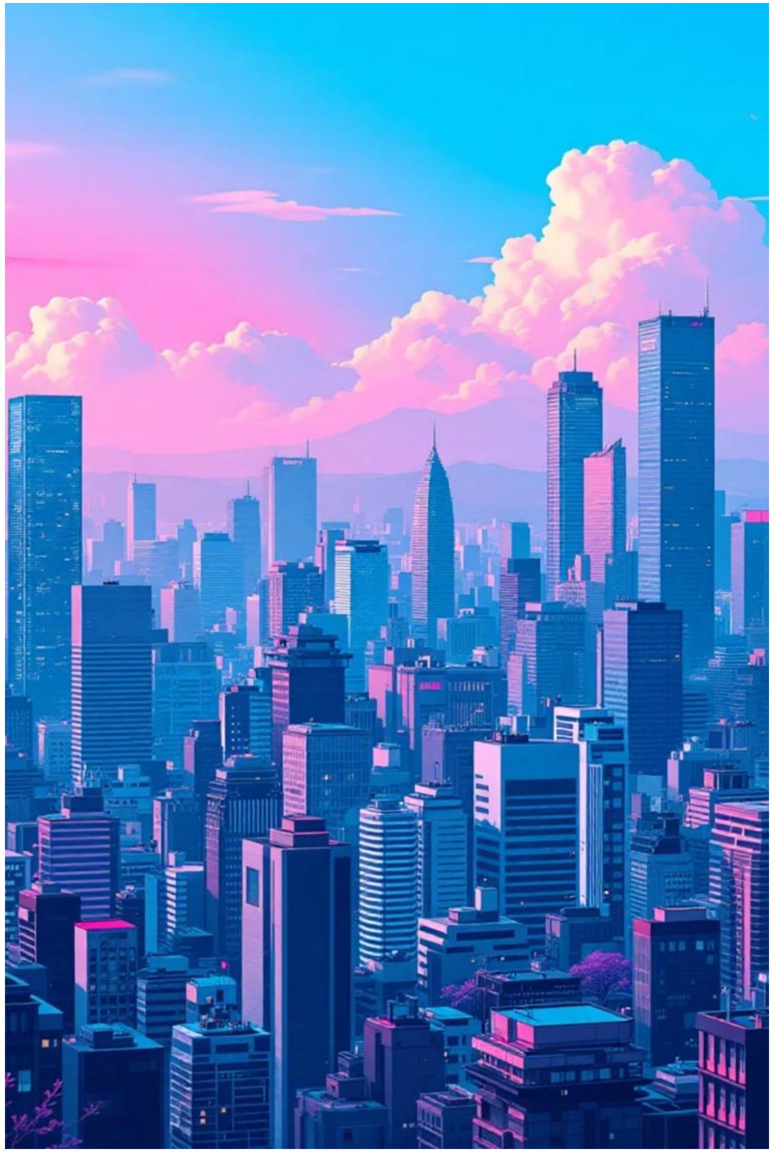
# Key Findings: GDP and Population Effects

## GDP Impact

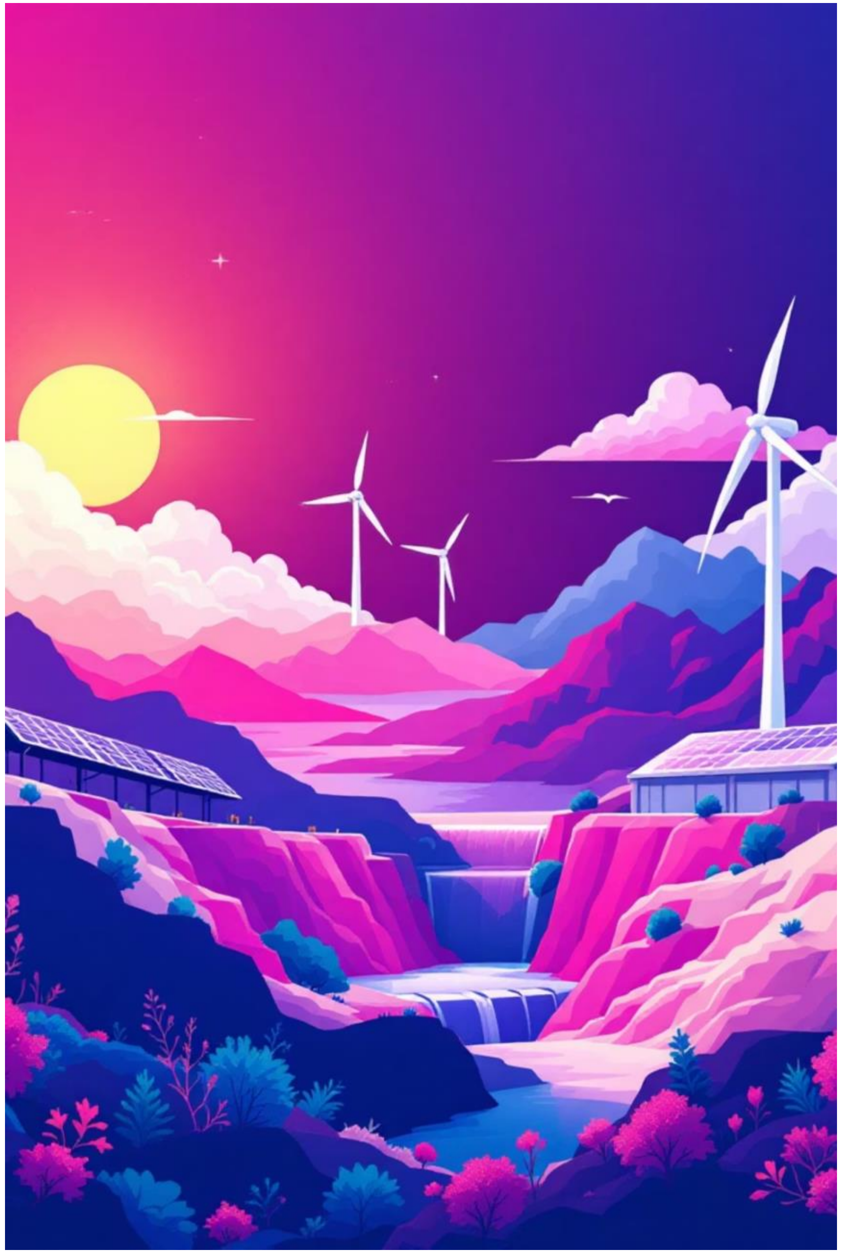
Negative correlation with Load Capacity Factor in Australia, Canada, and UK. USA shows positive correlation until 2000s, then reverses—linked to policy shifts and shale revolution prioritizing growth over environment.

## Population Impact

Generally negative across all countries except UK, where developed environmental policies and efficient resource management enable positive outcomes despite high population density.



# Green Innovation and Renewable Energy Results



## Environmental Patents

Consistently positive impact on LCF across all countries. Green technology adoption drives energy efficiency and carbon reduction, demonstrating long-term sustainability benefits.

## Renewable Energy

Positive correlation in Australia, Canada, USA via wavelet analysis. However, WQR shows adverse effects in Australia, Canada, USA—attributed to incomplete energy transitions and high fossil fuel dependence.

## UK Exception

Only country where renewables and labor productivity improve LCF, reflecting strong green policies, grid infrastructure, and efficient resource management.

# Labor productivity: efficiency vs. scale effects

Labor productivity's impact varies dramatically by country,
revealing a critical tension between efficiency gains and production expansion:

### UK & Australia

Positive correlation: Productivity improvements reduce waste and energy intensity through better management and technology adoption.

### Canada & USA

Negative correlation: Productivity gains drive higher output volumes, enlarging ecological footprint despite efficiency improvements.

### The Paradox

Profit-driven productivity in carbon-intensive sectors can degrade environment even as efficiency metrics improve.

# Policy recommendations for sustainable development

## 1 Incentivize Green Patents

Establish systems supporting environmental technology development—consistent positive impact on LCF across all nations.

## 2 Invest in Renewable Infrastructure

Direct subsidies toward renewable energy, particularly in resource-rich nations. Requires tailored strategies for diverse economic contexts.

## 3 Decouple Growth from Footprint

Strengthen environmental standards, prioritize green sectors, and prevent "dirty" economic growth through innovation and policy.

## 4 Align Productivity with Ecology

Develop programs ensuring productivity gains reduce resource intensity, not increase absolute consumption and environmental impact.

# Conclusion: Context-Specific Sustainability

Sustainable development requires tailored strategies reflecting each nation's unique economic structure, environmental capacity, and policy framework. Green patents consistently enhance environmental quality. However, renewable energy and productivity impacts vary—beneficial in the UK's developed system, detrimental in Australia, Canada, and USA where structural factors and growth models dominate. Success demands coordinated policy innovation, technological progress, and integration of renewable energy sources adapted to local circumstances.

**Natalia Veselitskaya,** PhD,
Leading Research Fellow,
HSE University, Russia
nveselitskaya@hse.ru