Assessing the changes in the impacts of electricity on climate change over time and across countries: A Functional Data Analysis Approach

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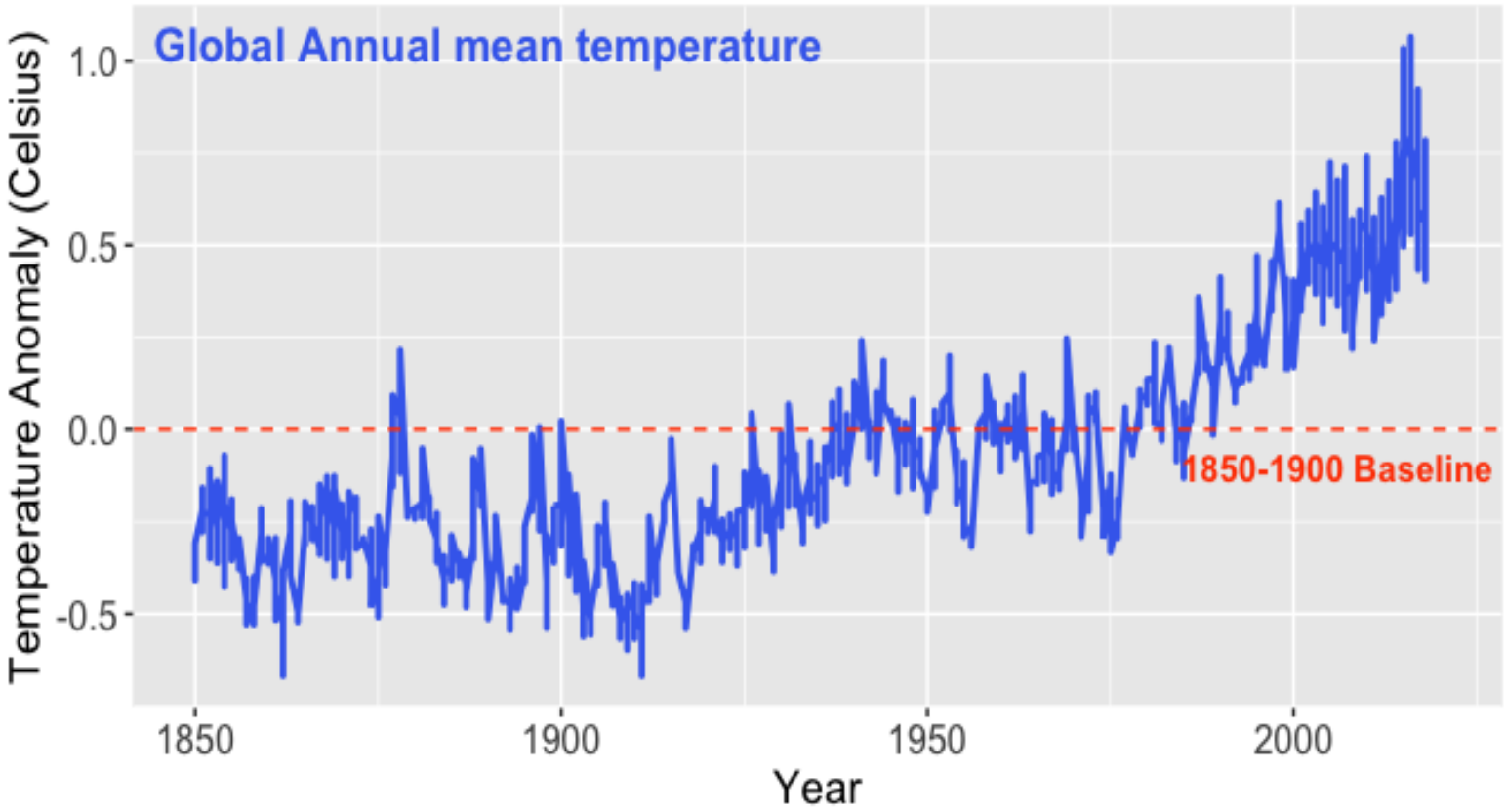

SDG13

Taking urgent action to combat climate change and its impacts.

Introduction

- To mitigate the impacts, we need to understand and quantify the impacts of human activities on the drivers of climate change.

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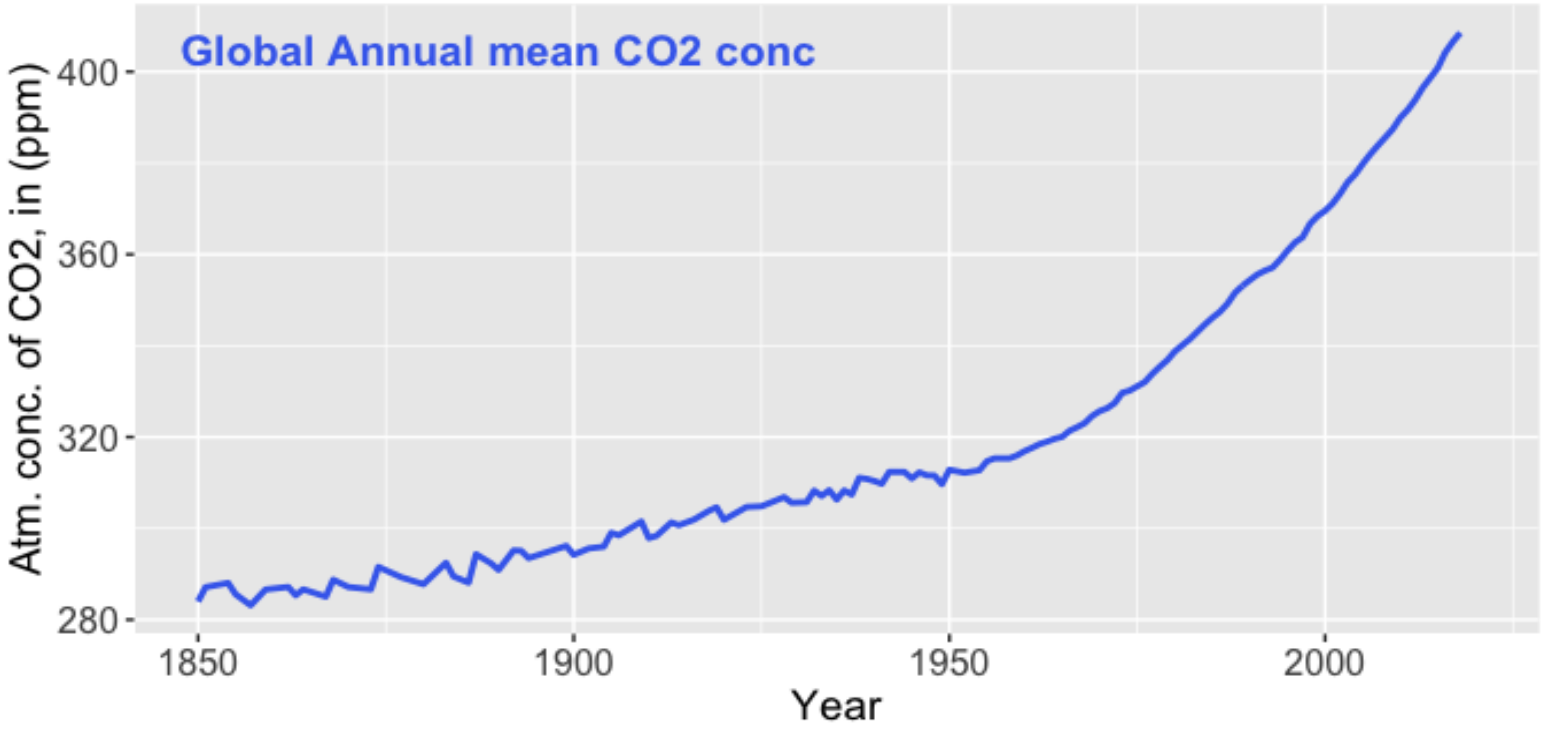
- The rise in global average temperature is mainly attributed to an increase in greenhouse gas emissions, **especially CO_2**.

- Since the industrial revolution, greenhouse gas emissions have increased **exponentially and simultaneously** with energy-production.



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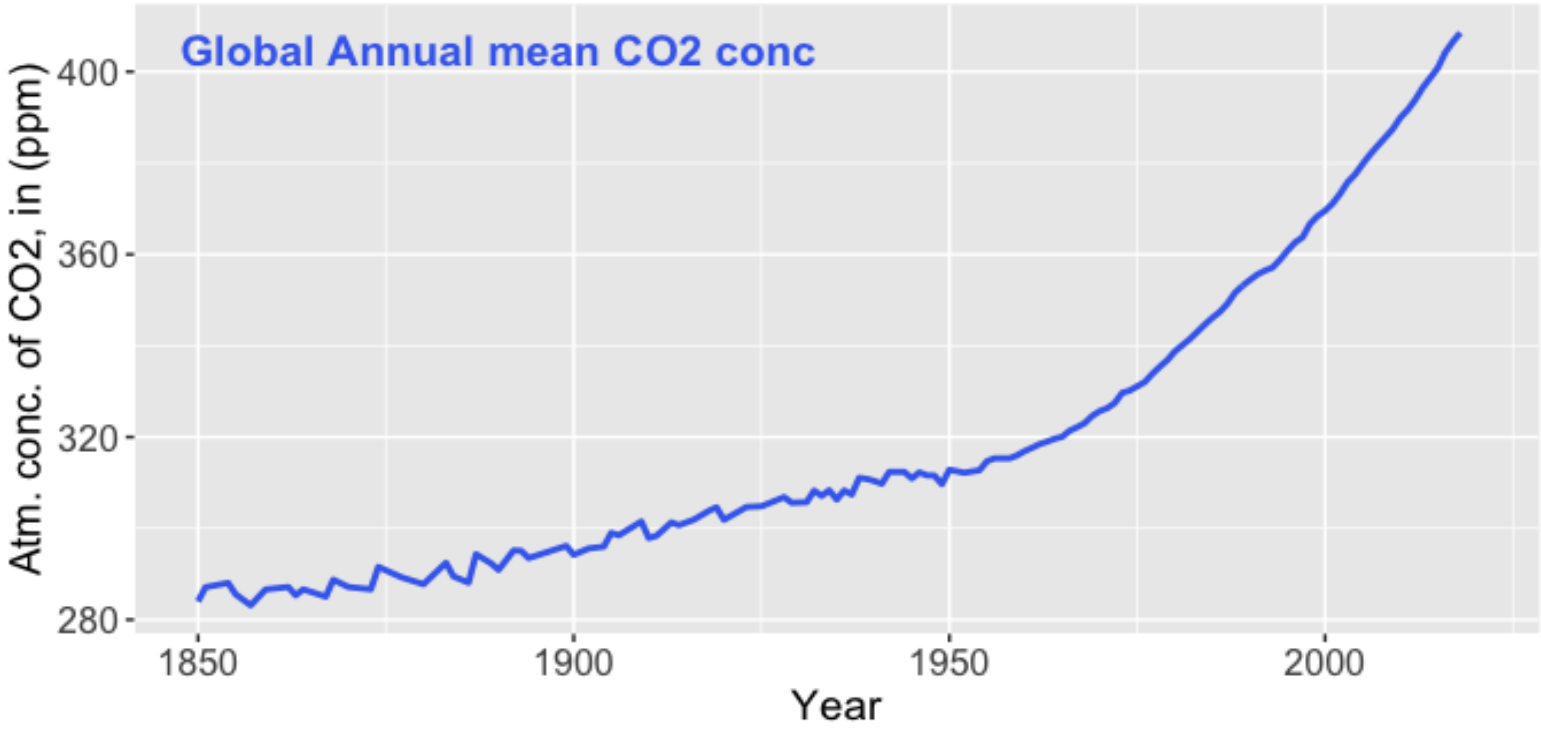
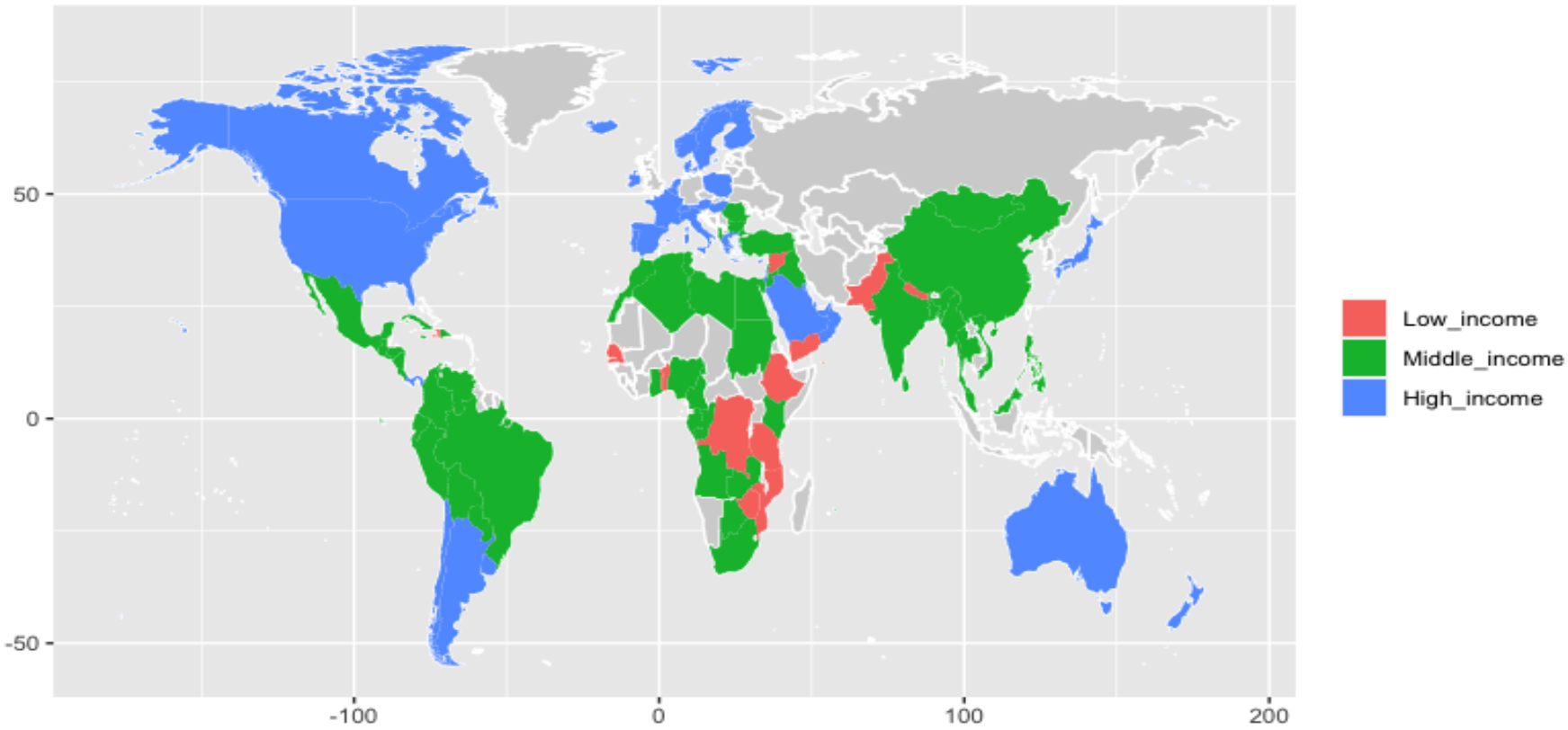


- CO_2 emissions primarily stems from burning fossil fuels e.g. oil, coal and gas for energy use.
- **China** is the world's largest emitter (25%), followed by the **USA** (18%).

Introduction

- **Electricity** is considered the main source of global CO_2 emissions; but this is also attributed to the methods used to produce electricity.
- Economic growth and industrial development are not the only drivers of CO_2 emissions but also **policy and technology choices**.

Data



For 108 countries from 1975-2014:

- Annual carbon dioxide emissions (kt) per capita.
- Annual electric power consumption (kWh) per capita.

Aims

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Using Functional Data Analysis

Why Functional Data Analysis?

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Functional Data Analysis

- Useful when dealing with highly **heterogeneous** data; allows each subject to determine its own functional structure.
- Able to handle **time-varying** relationships among variables.
- Powerful in visualizing and capturing **complex** data patterns.

Functional Data Analysis (FDA)

In FDA, data are viewed as the realizations of a functional stochastic process $X_i(t) : i \in \mathbb{Z}, t \in \mathcal{T}$, where:

- i is a **discrete** parameter denoting **country**.
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- $X_i(t)$ is obtained by **smoothing** raw data.

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Discrete data

$$
\begin{array}{lcccc}
\text{country}_1 & x_{1,1} & x_{1,2} & \dots & x_{1,m} \\
\text{country}_2 & x_{2,1} & x_{2,2} & \dots & x_{2,m} \\
\vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots \\
\text{country}_n & x_{n,1} & x_{n,2} & \dots & x_{n,m}
\end{array}
$$

set of points in $\mathbb{R}^p$

$p < \infty$

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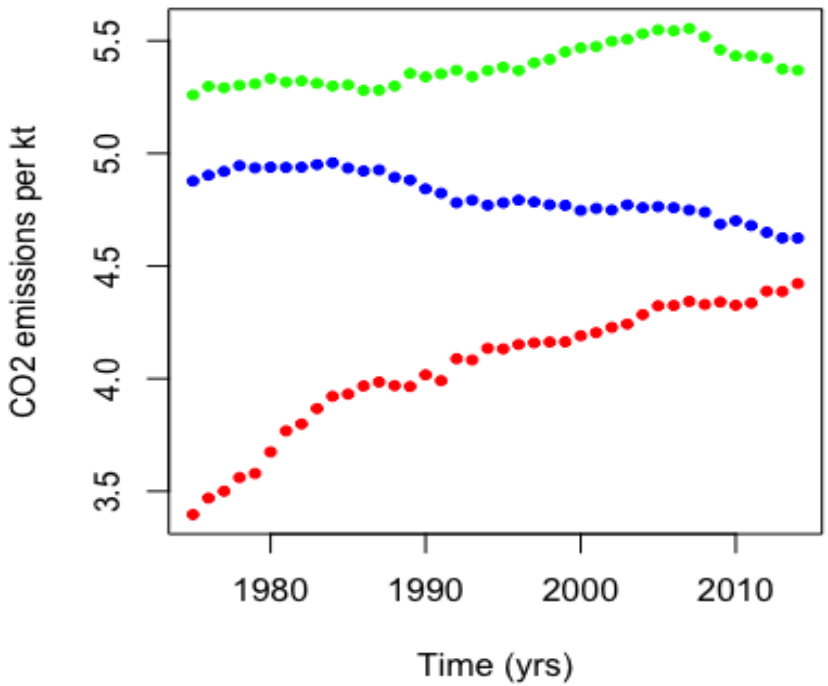
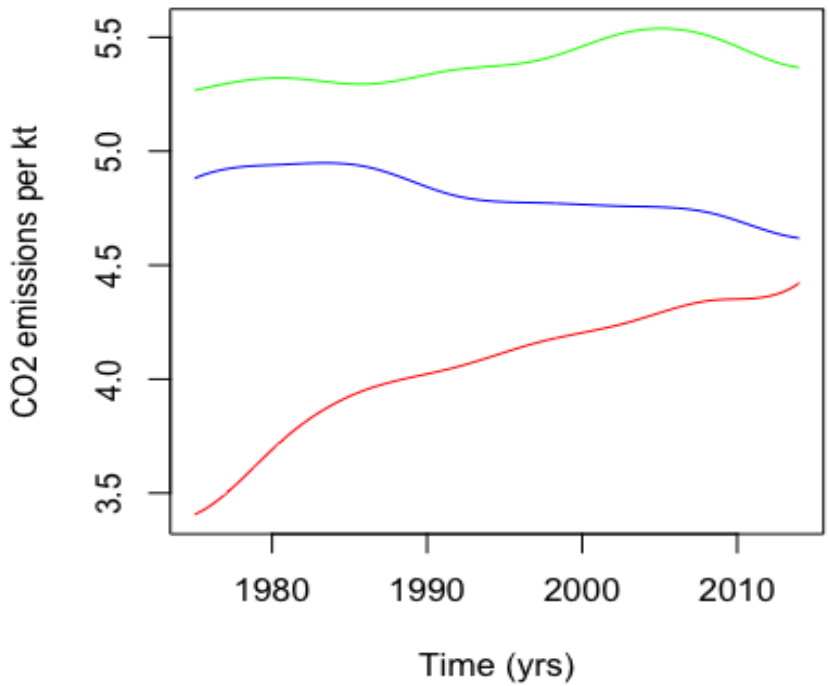
	Discrete data					**Functional data**
country_1	$x_{1,1}$	$x_{1,2}$	$\dots$	$x_{1,m}$		$x_1(t)$
country_2	$x_{2,1}$	$x_{2,2}$	$\dots$	$x_{2,m}$		$x_2(t)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\Longrightarrow$	$\vdots$
country_n	$x_{n,1}$	$x_{n,2}$	$\dots$	$x_{n,m}$		$x_n(t)$
	set of points in $\mathbb{R}^p$					set of functions on $\mathcal{T}$
	$p < \infty$					$p = \infty$

Functional Data Analysis (FDA)





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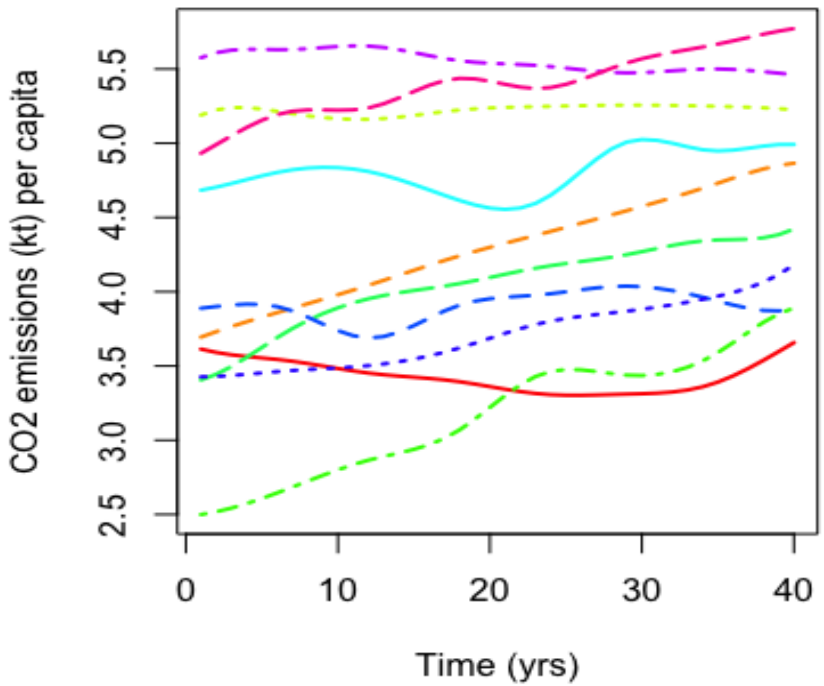

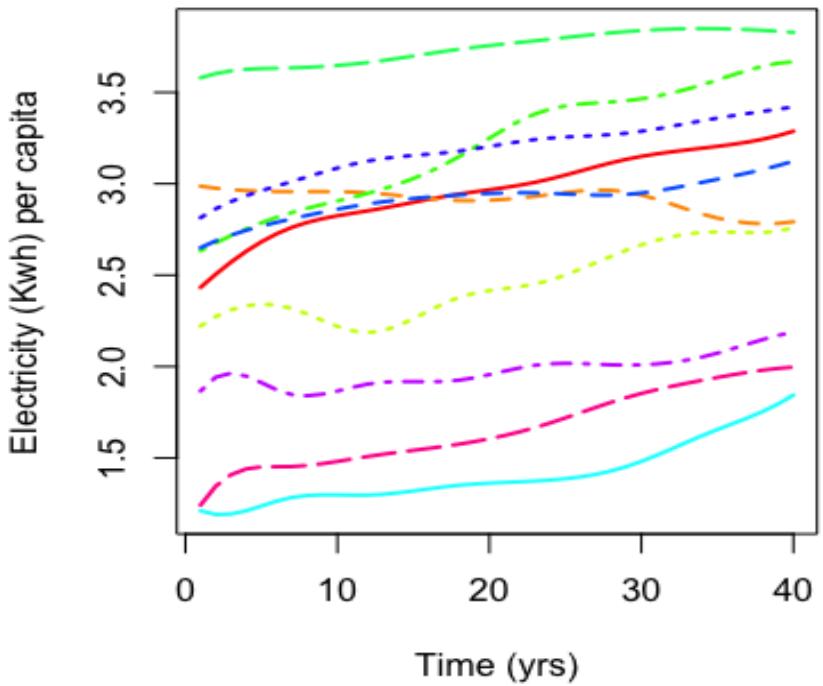

Tools in Functional Data Analysis (FDA)

- **Functional Principal Component Analysis**
  - Identify the primary sources of variations in a set of curves.

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- **Functional Principal Component Analysis**
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    $\Longrightarrow$ What are the sources of differences between countries' trends?

- **Functional Regression**
  - Explain how relationships between (functional) response and explanatory vars varied over the functional domain (time).

    $\Longrightarrow$ How the relationship between electricity consumption and CO_2 emissions evolved over time?

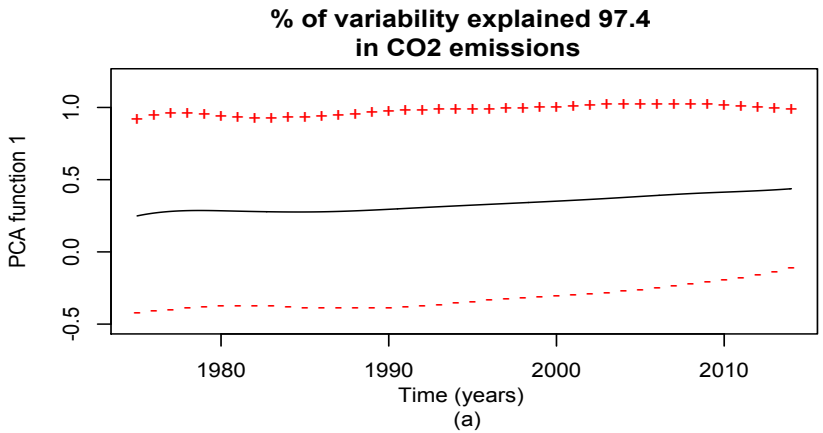
FPCs are obtained via the eigen-decomposition of the covariance

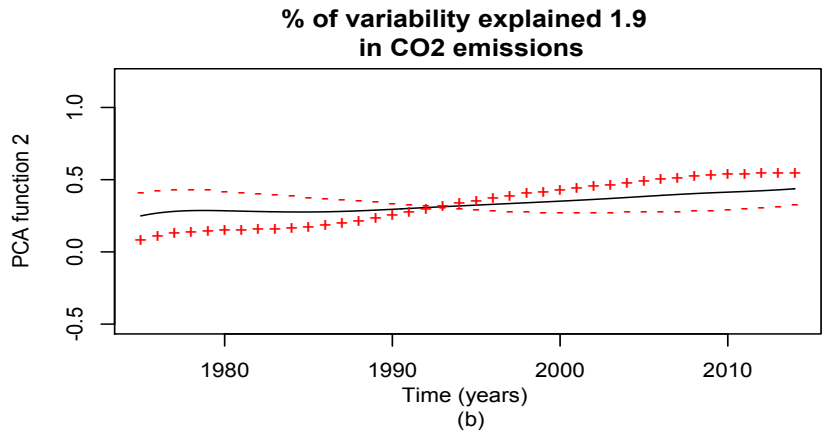
$$\int v(s,t)\xi(t)dt = \lambda\xi(s),$$

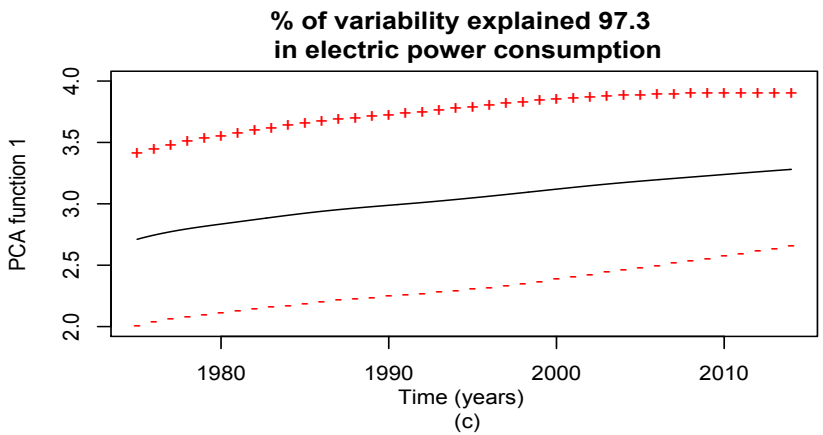
where

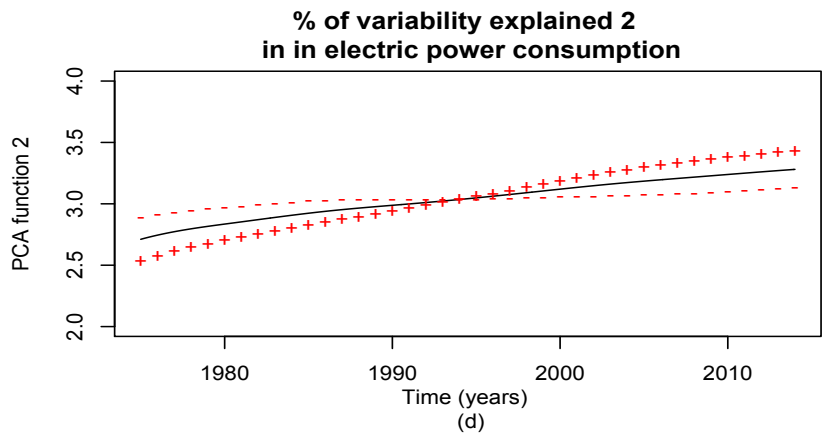
- $v(s,t)$ is the **covariance function** across curves between time points s and t.
- λ and $\xi(.)$ are the eigenvalues and **eigenfunctions** obtained such that λ_j (non-decreasing) > 0 ; $\int_{\mathcal{T}} \xi_j^2(t)dt = 1$; $\int_{\mathcal{T}} \xi_j(t)\xi_{j'}(t)dt = 0$

FPCA (Results)









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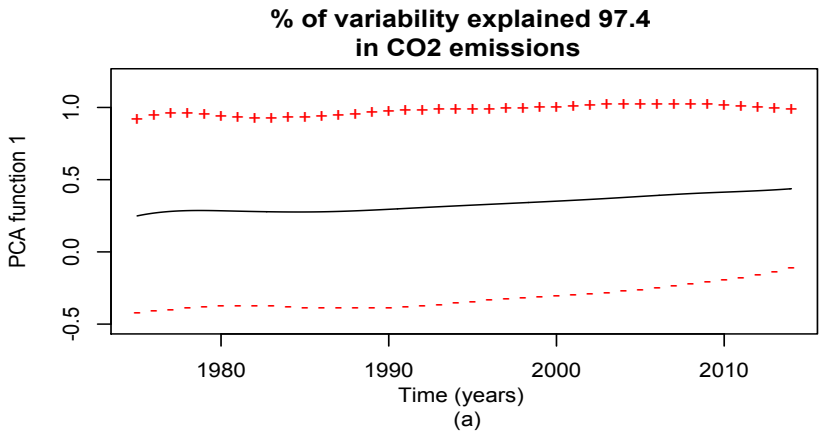
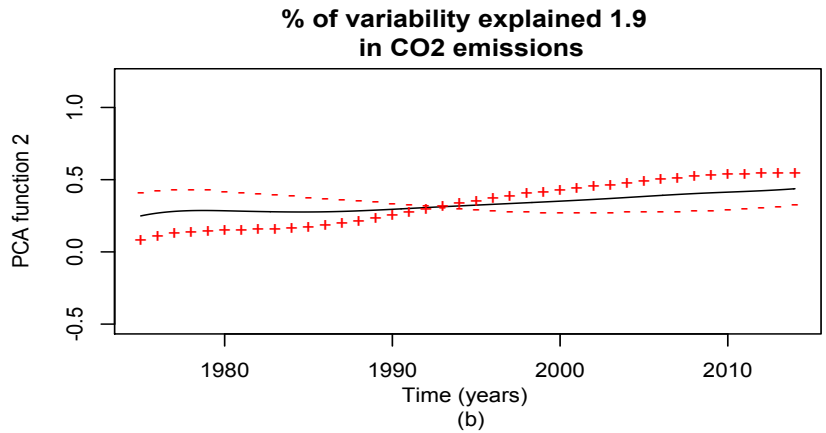
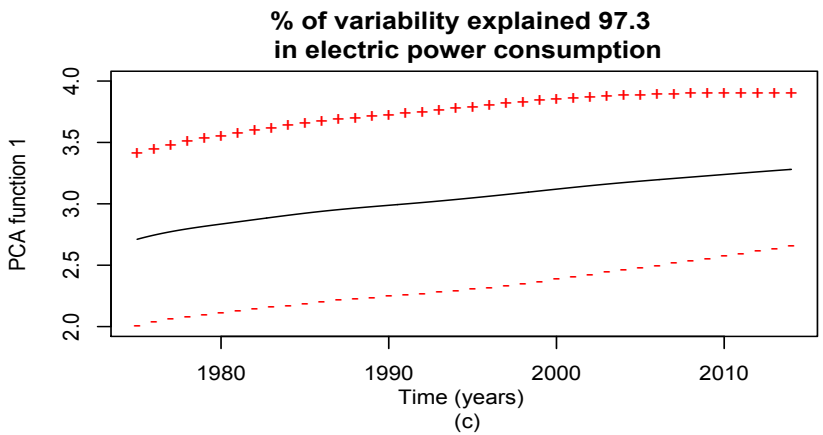
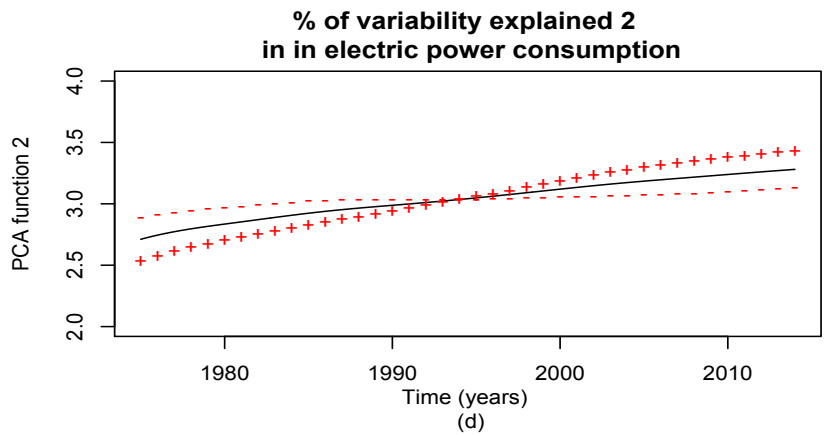




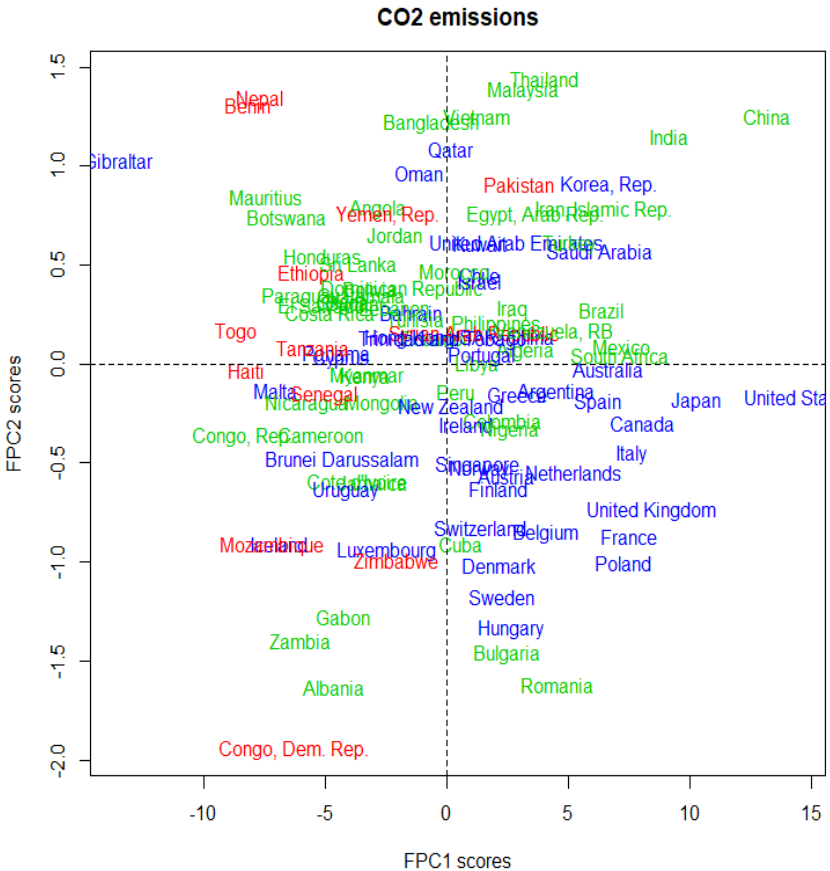


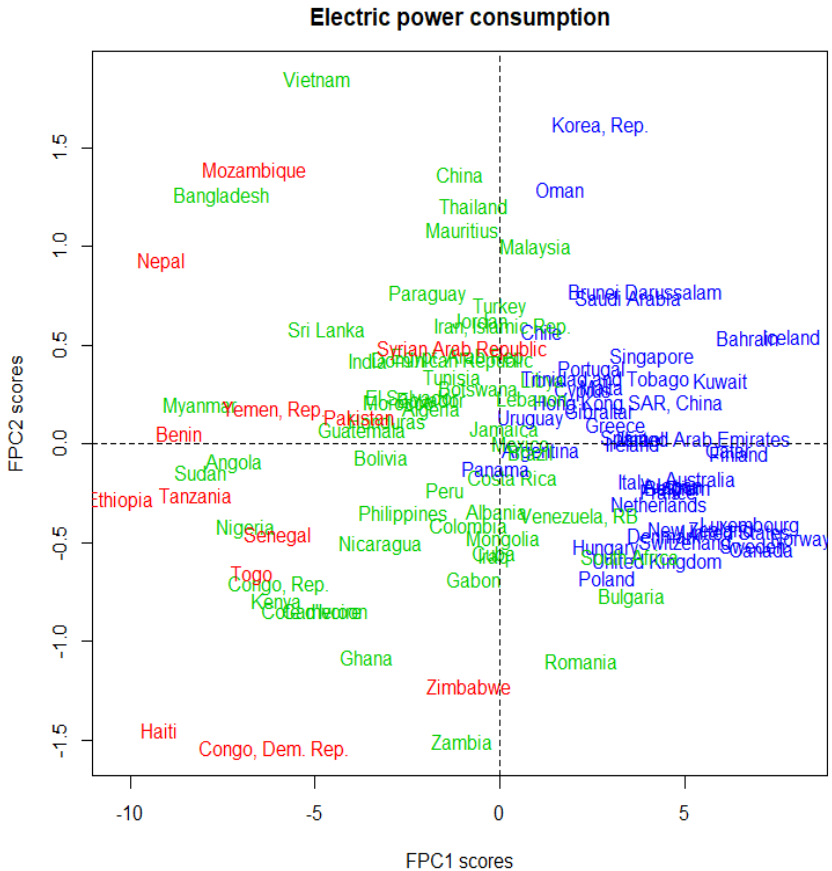


Discrepancies between countries' trends are attributed to:

- the deviations from the mean level; and
- the contrast between the period 1975 - 1990 and post 1990.

FPCA (Results)





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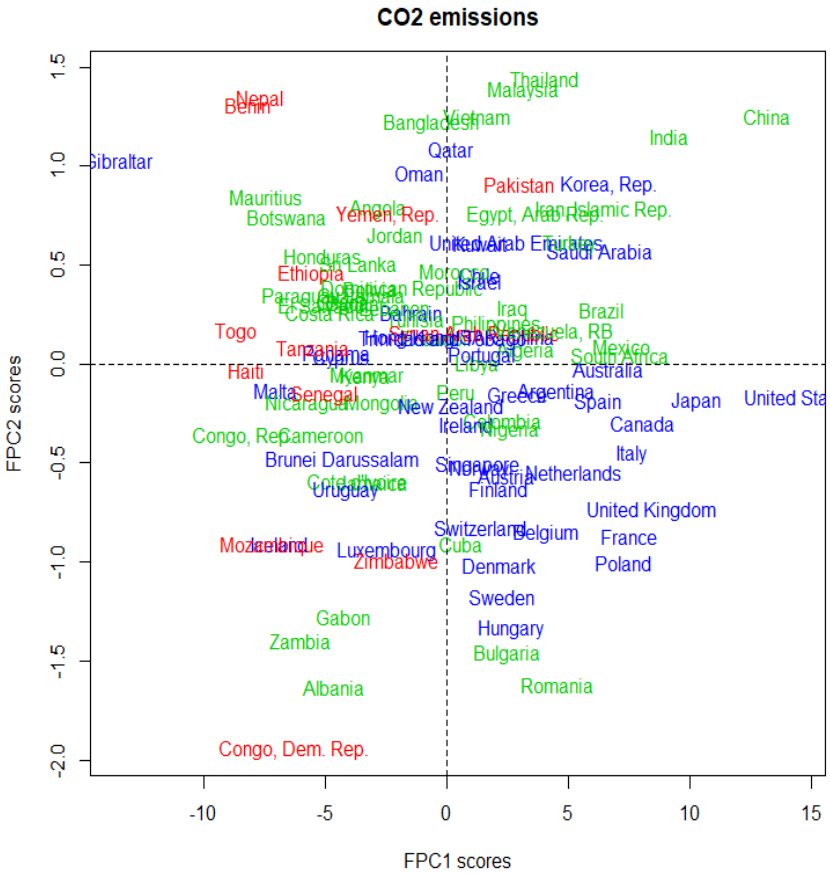

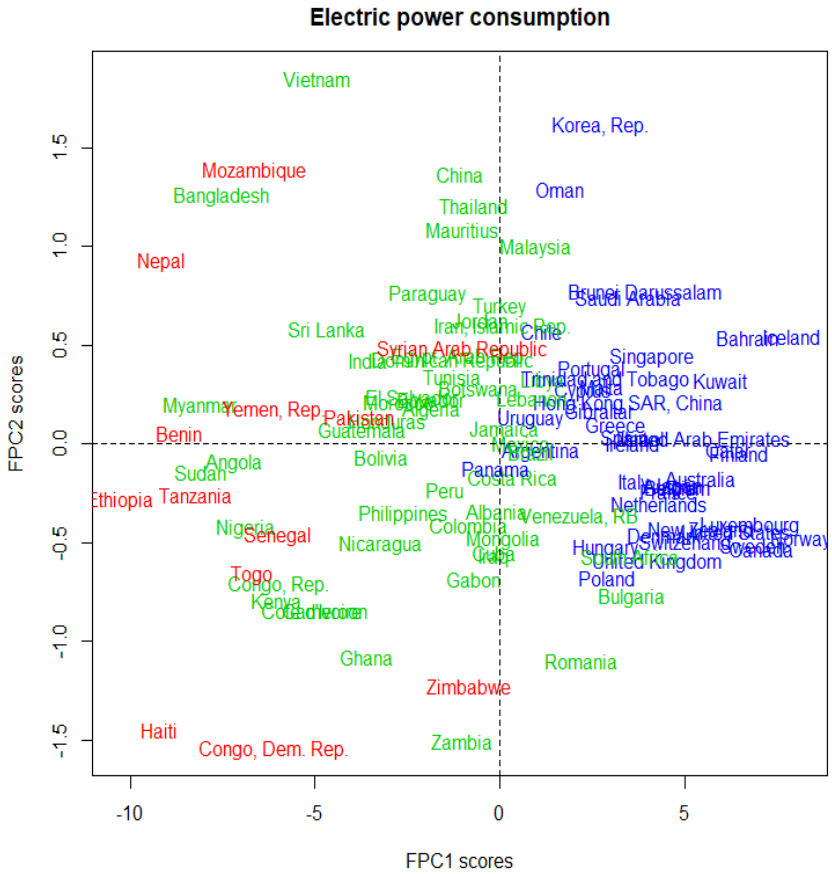

- Despite increasing electric consumption, high-income European countries managed to reduce their CO_2 emissions over time (esp. after 1990).

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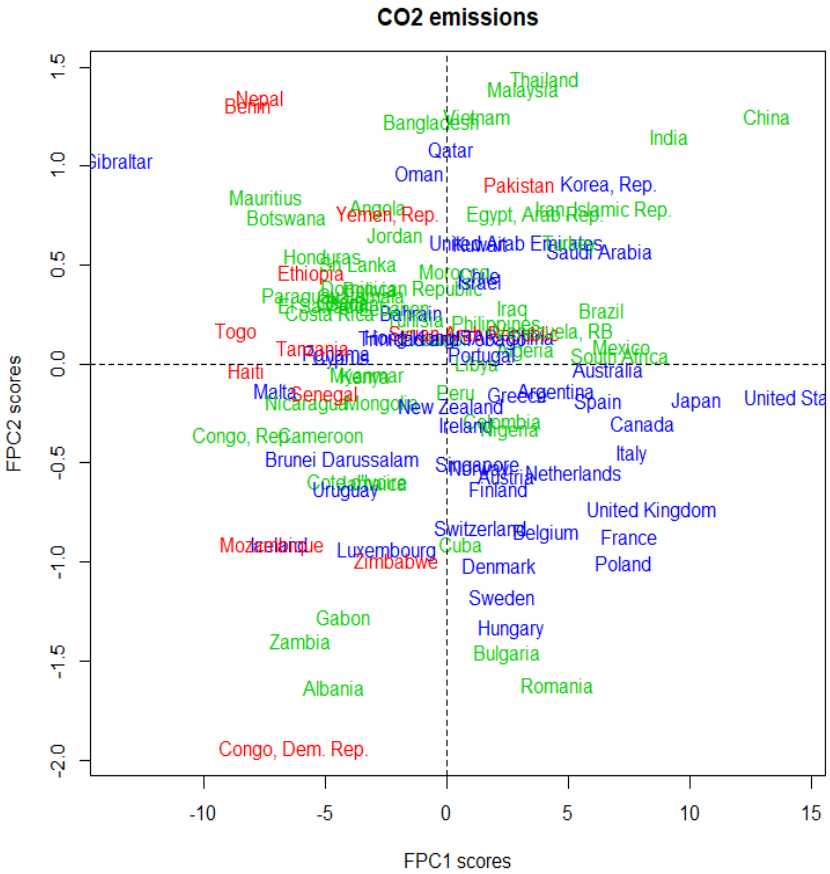

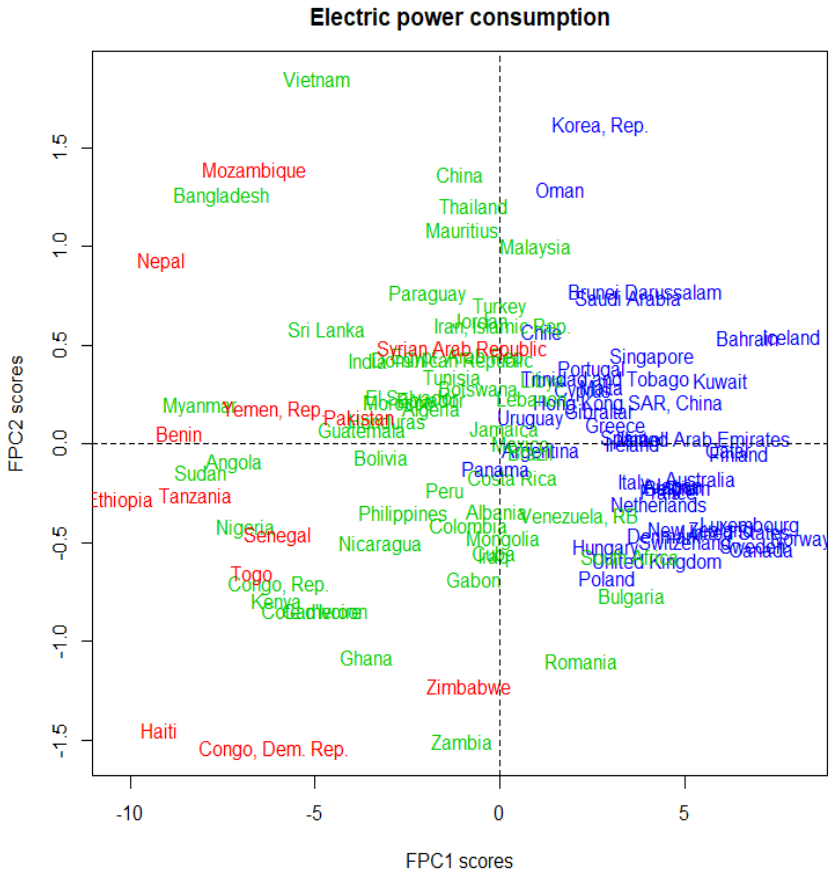

- Despite increasing electric consumption, high-income European countries managed to reduce their CO_2 emissions over time (esp. after 1990).
- China, India and Gulf countries continue to emit high CO_2 emissions.

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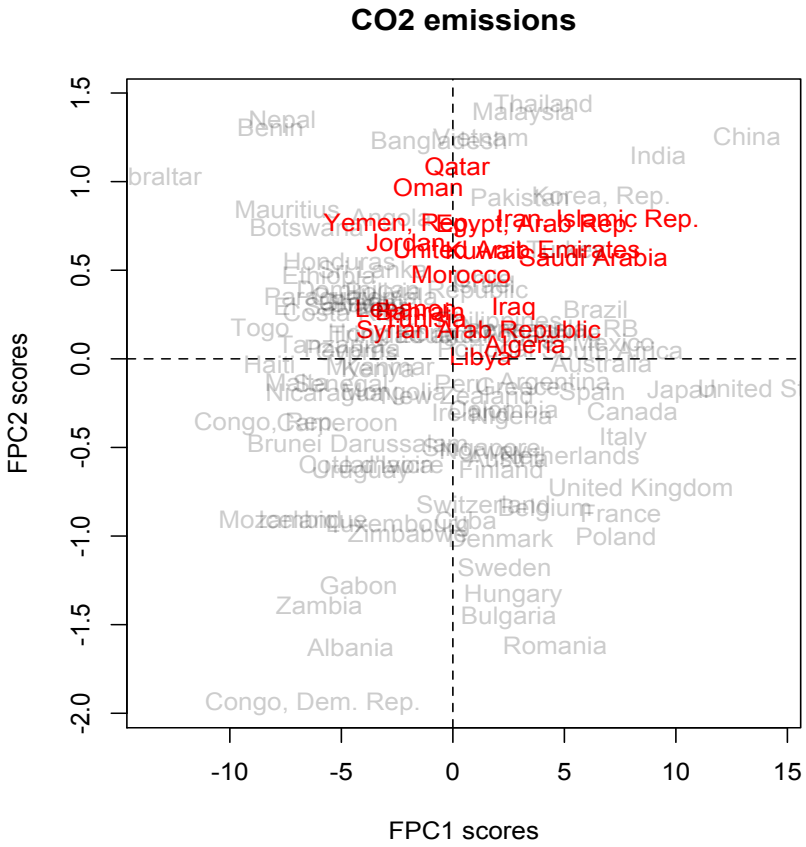

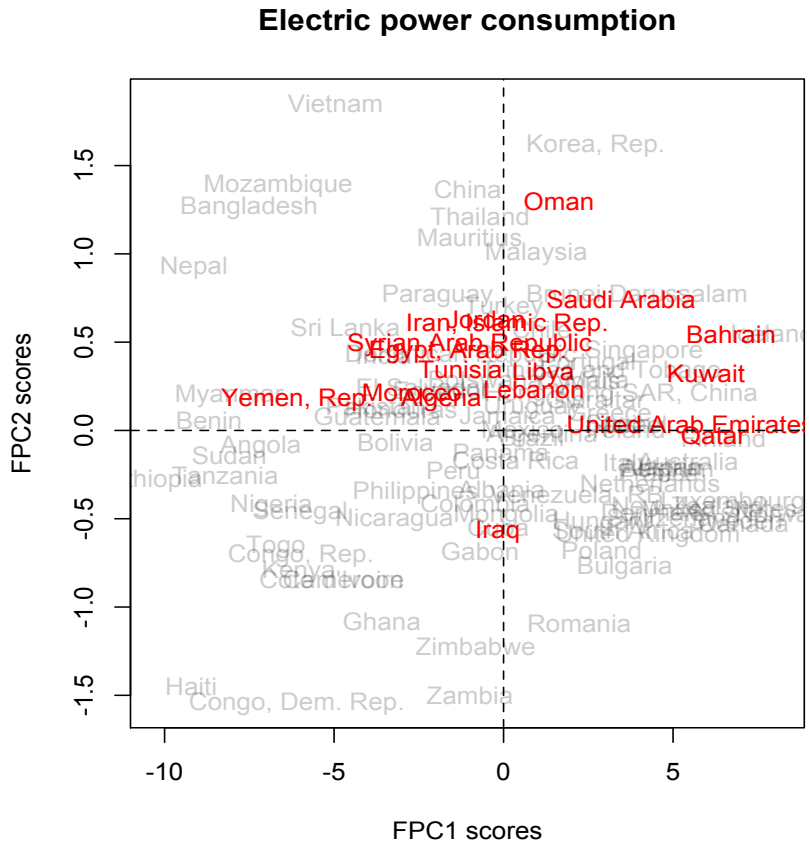

- All MENA countries continually emit increasing CO_2 emissions regardless of income group; highlighting consequences of development.

The model of interest here is:

$$\text{CO2}_i(t) = \beta_0(t) + \beta_1(t)\text{Electric Consumption}_i(t) + \beta_2(t)\text{GDP}_i(t) + \epsilon_i(t),$$

where $\beta_0(t), \beta_1(t), \beta_2(t)$ are the regression coefficients **functions**.

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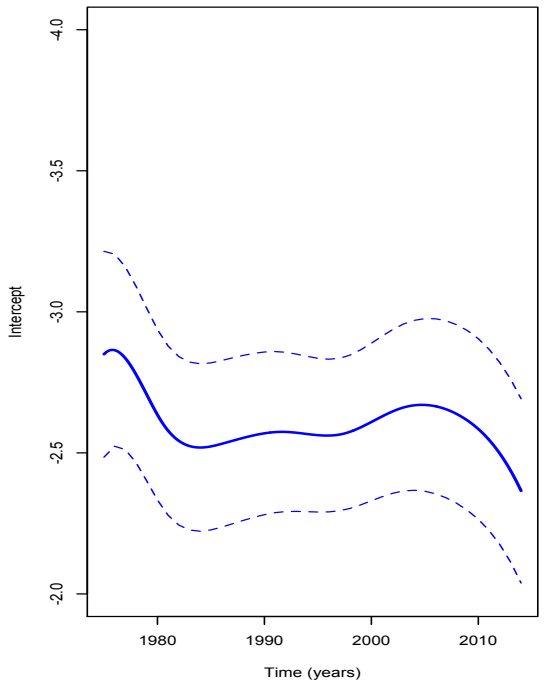
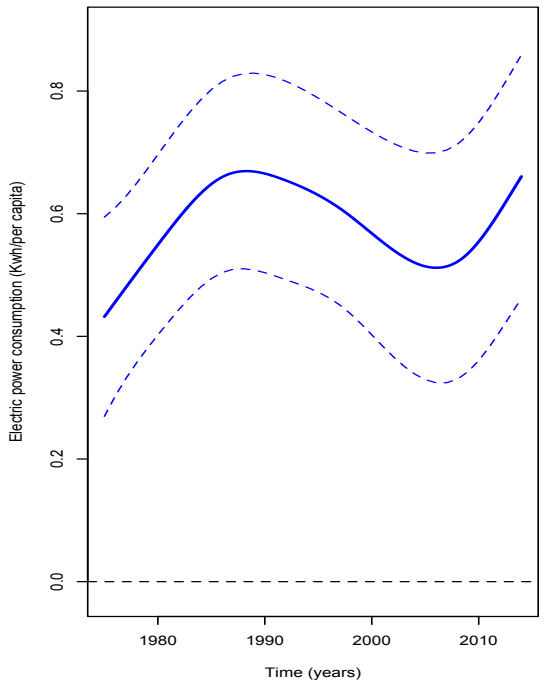
- It has both the response and the covariates as **functions of time**.
- It relates the response function **at a specific point** to the covariate value **at the same point**.

Functional Regression (Results)

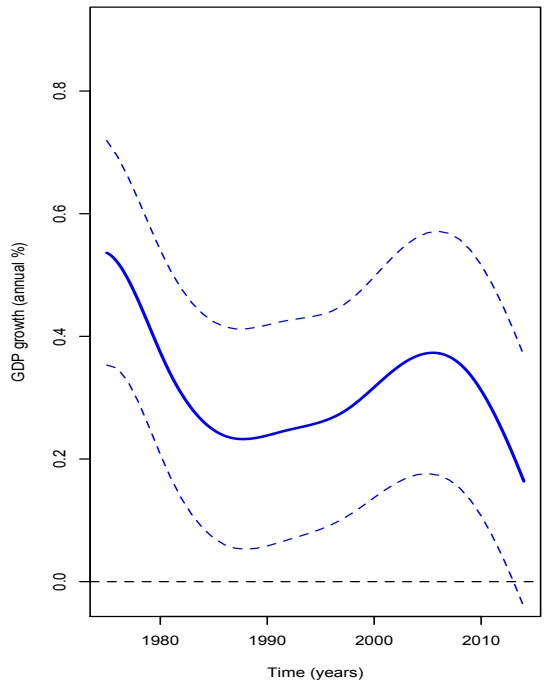
$\beta_0(t)$



$\beta_1(t)$



$\beta_2(t)$



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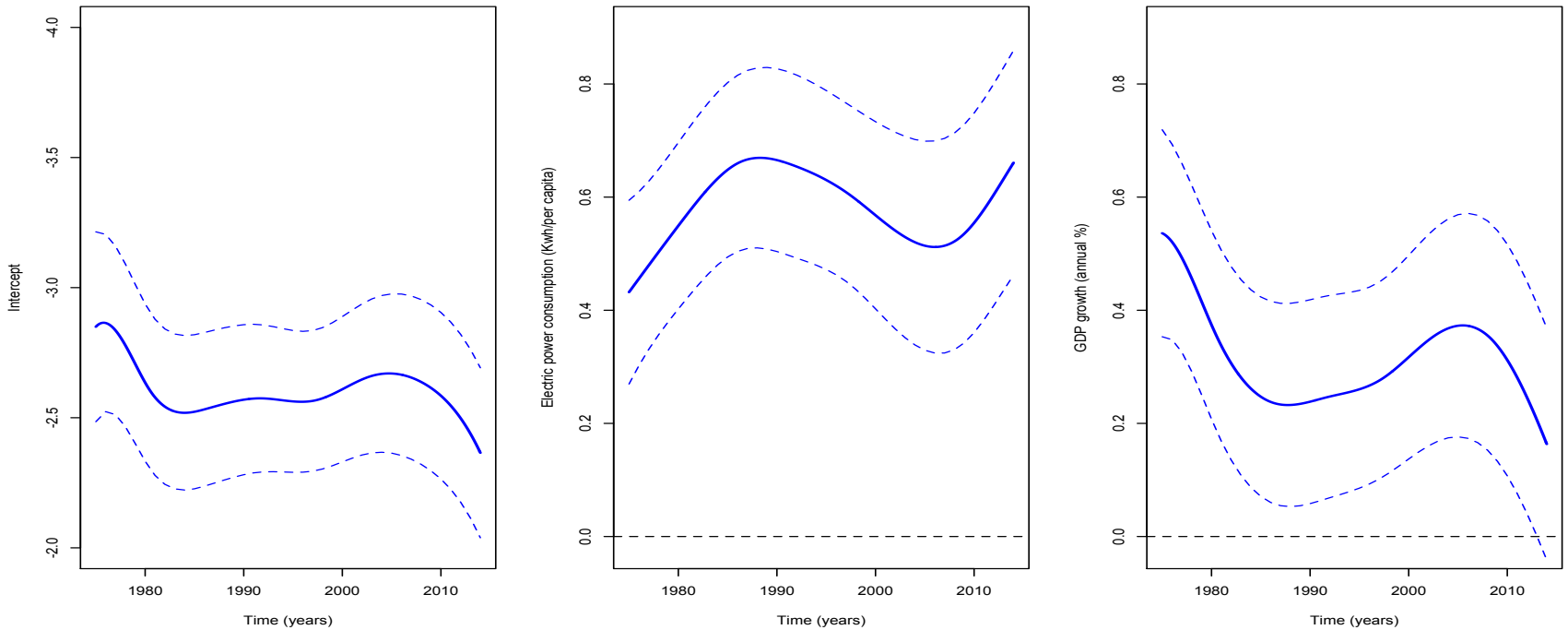

- The influence of electric consumption and GDP on CO_2 emissions vary over time.

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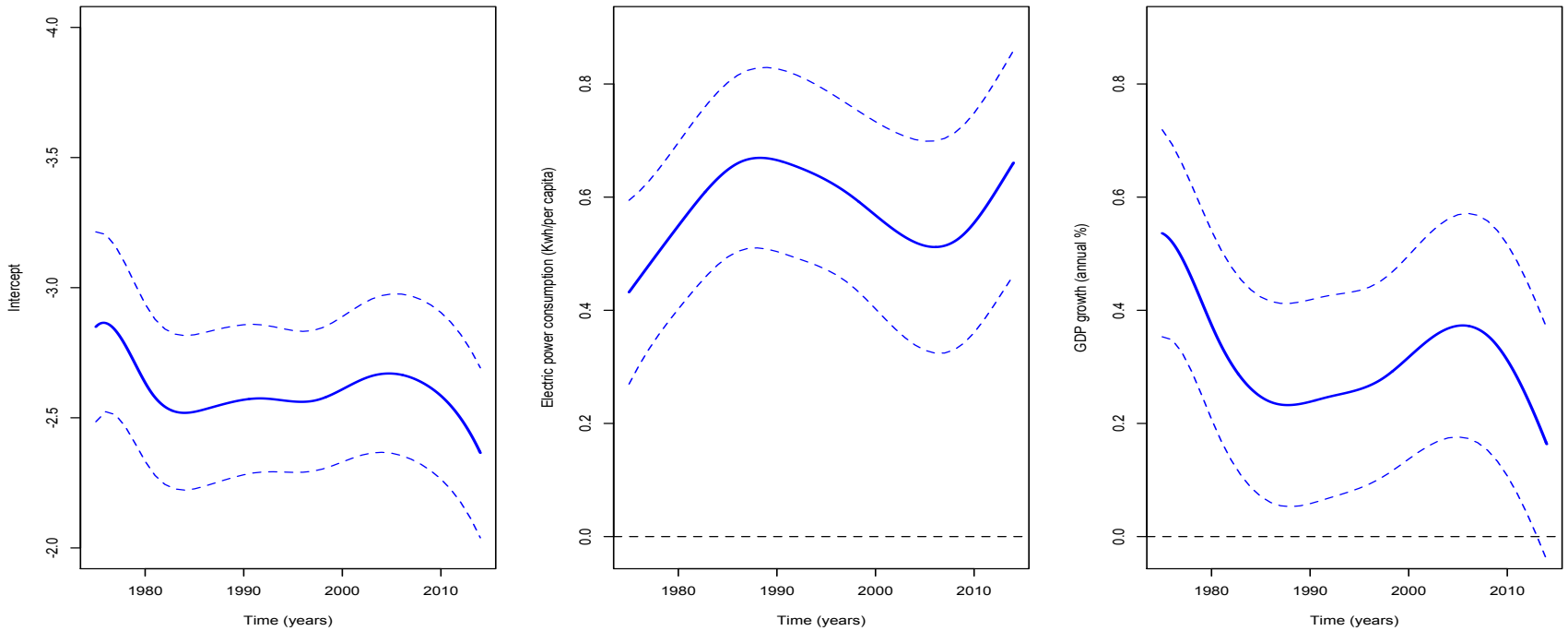
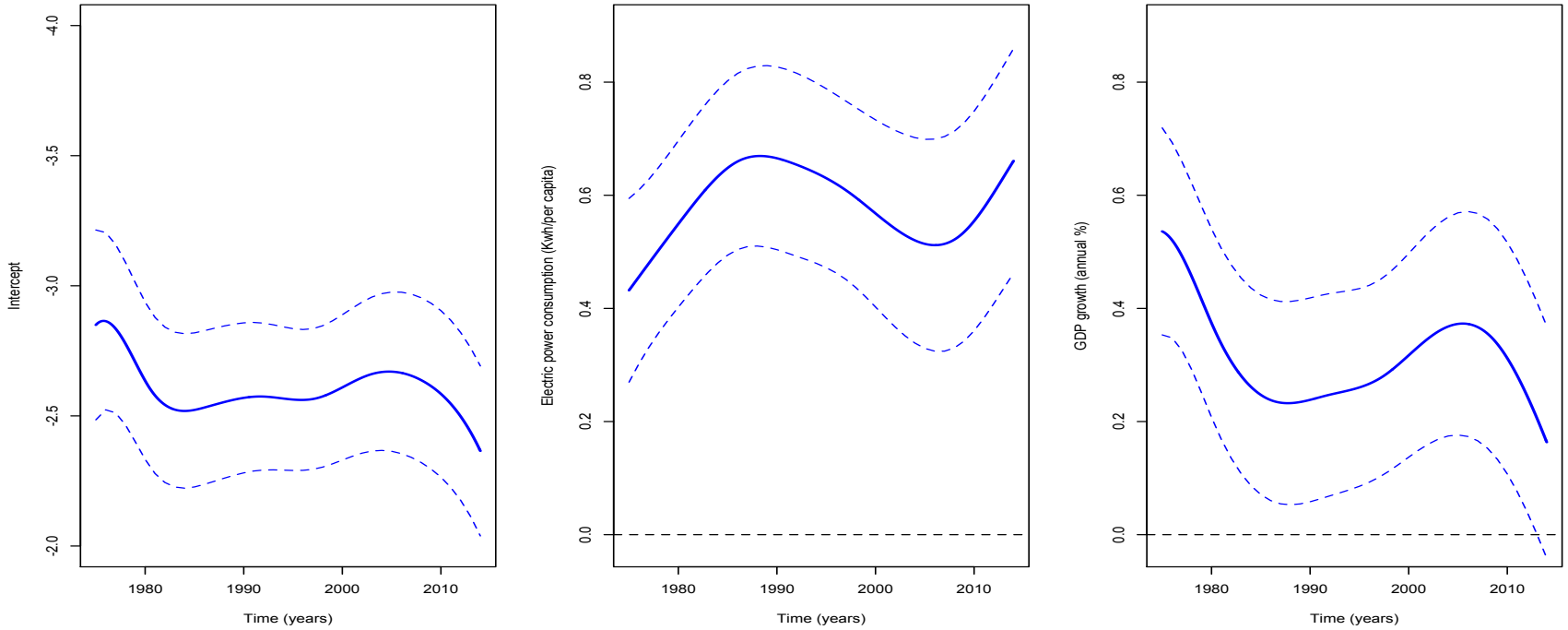


- The influence of electric consumption and GDP on CO_2 emissions vary over time.
- The influence of electricity dropped between 1990 and 2006 and increased slightly afterwards.

Functional Regression (Results)

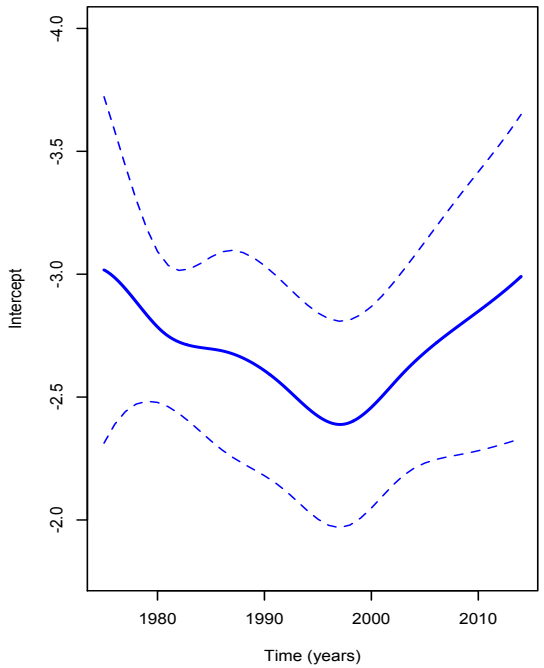
$\beta_0(t)$ $\beta_1(t)$ $\beta_2(t)$



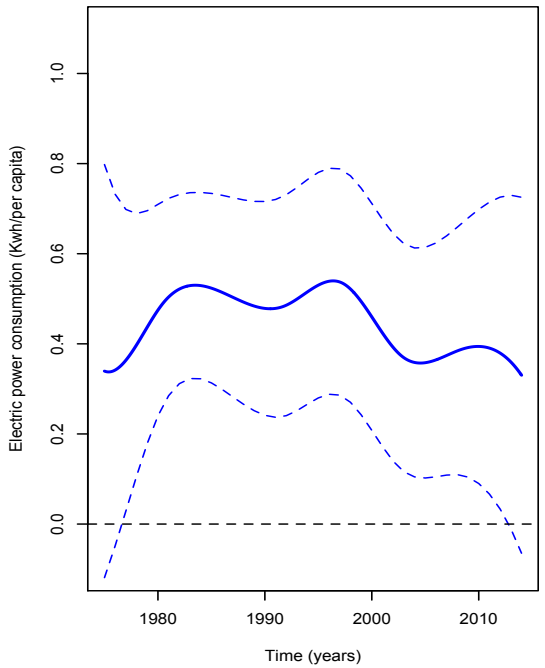
- The influence of electric consumption and GDP on CO_2 emissions vary over time.
- The influence of electricity dropped between 1990 and 2006 and increased slightly afterwards.
- The influence of GDP increased between 1990 and 2006 then started to drop afterwards.

Functional Regression - MENA region (Results)

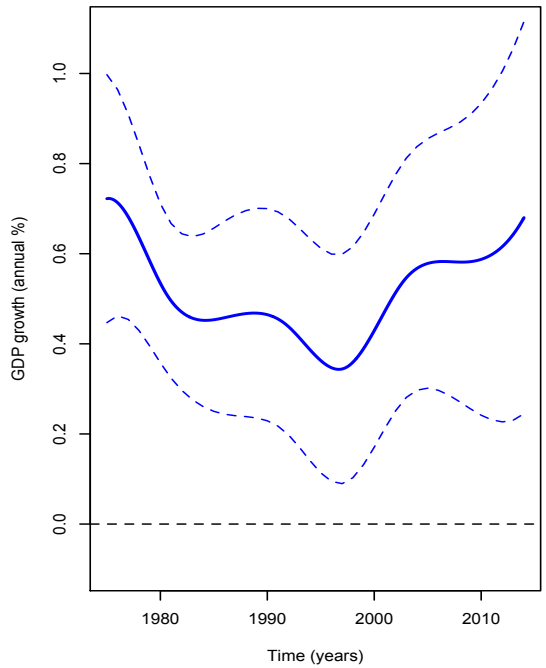
$\beta_0(t)$



$\beta_1(t)$

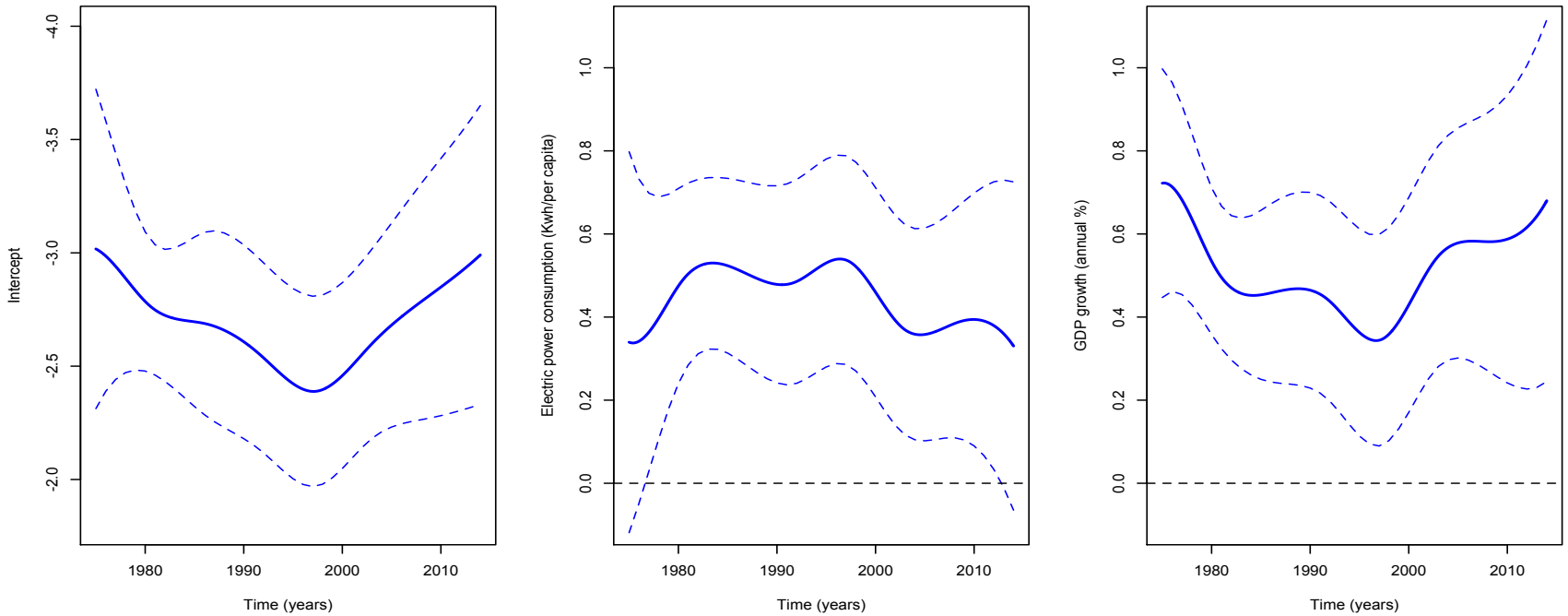


$\beta_2(t)$



Functional Regression - MENA region (Results)

$\beta_0(t)$ $\beta_1(t)$ $\beta_2(t)$



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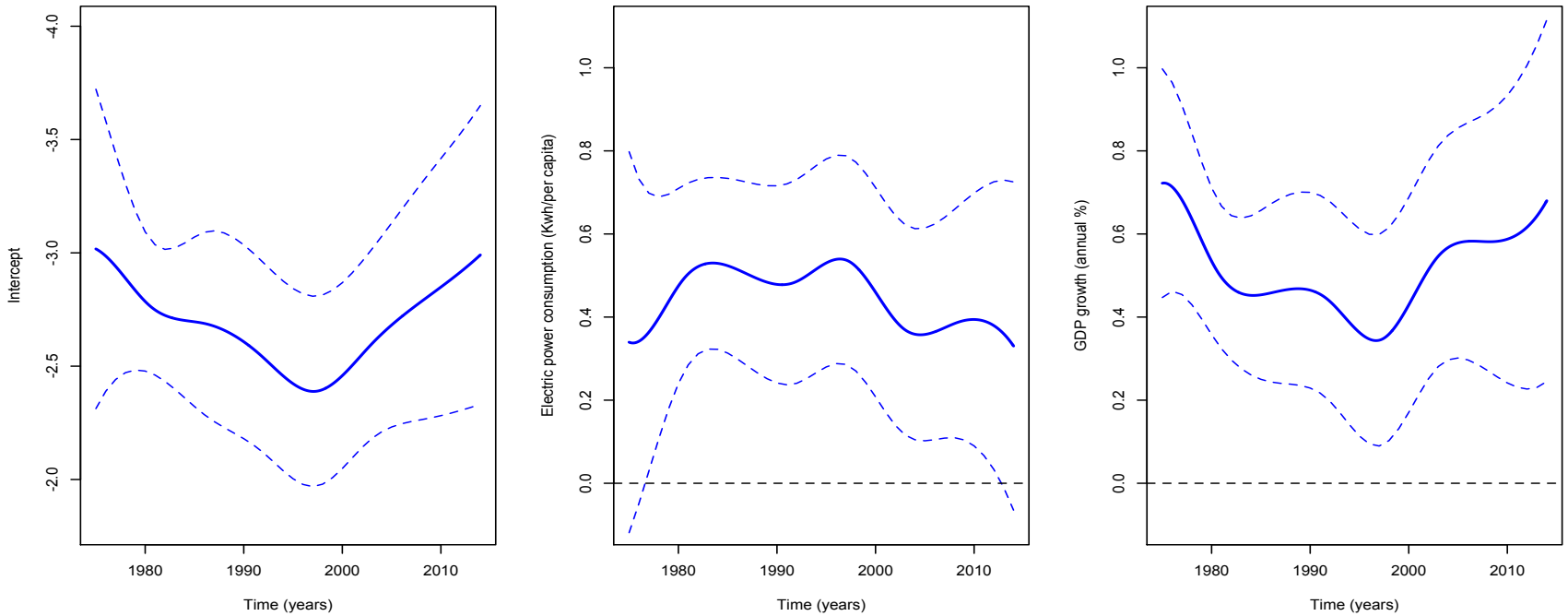

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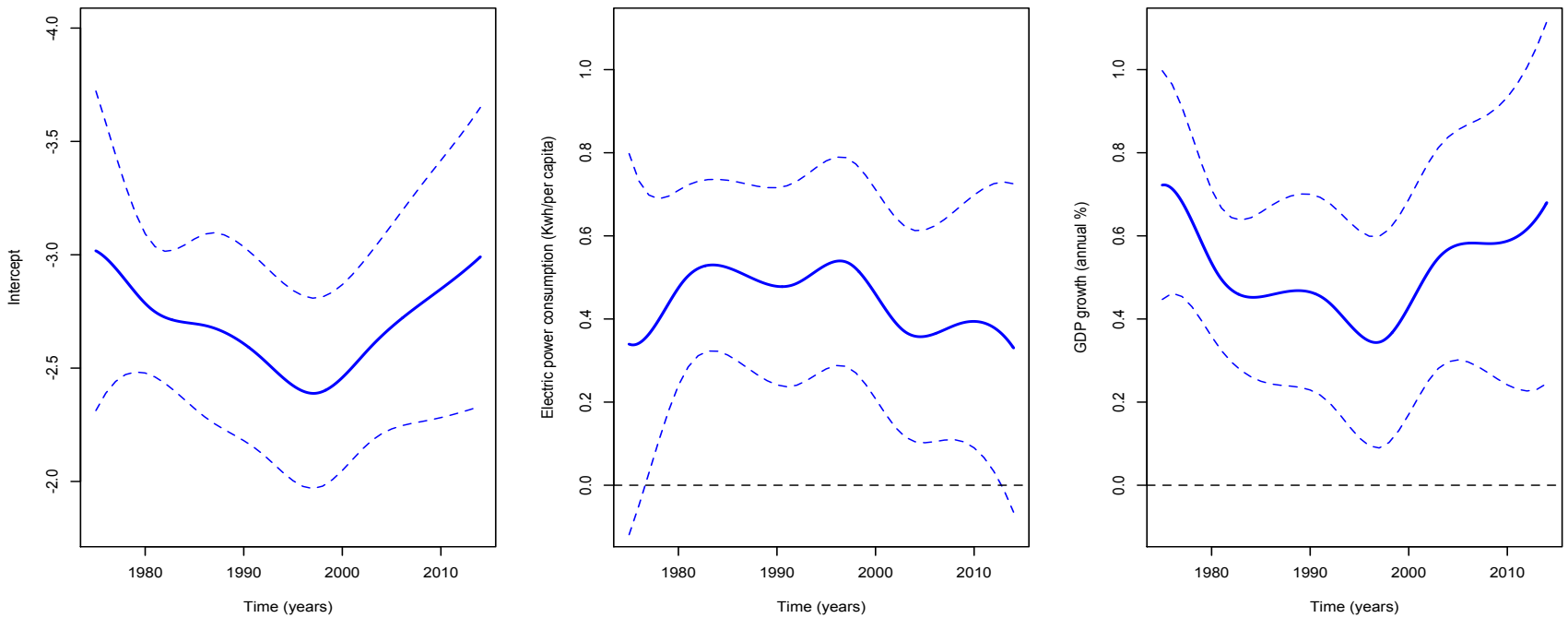

- Average CO_2 increases since 2000 simultaneously with an increase in the influence of GDP. **(Reforms + Early stage of EKC)**
- The influence of electric consumption remains almost the same over the study period.
- More variability between MENA region countries in the recent years.

Conclusions

- **Highly developed countries inc. USA, Canada, Japan & Europe** managed to reduce their per capita emissions over time since 1990 along with economic growth.

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Policy implications

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Policy implications

- Incentivise industries to adopt more energy efficient technologies.

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- Increase the capacity of renewables (Windfarms and Solar electricity). Expensive!
- Targeted investment in innovation - opportunities for new business, exports, jobs and a cleaner environment.