A switching regime model for the marginal emission factor MEF estimation

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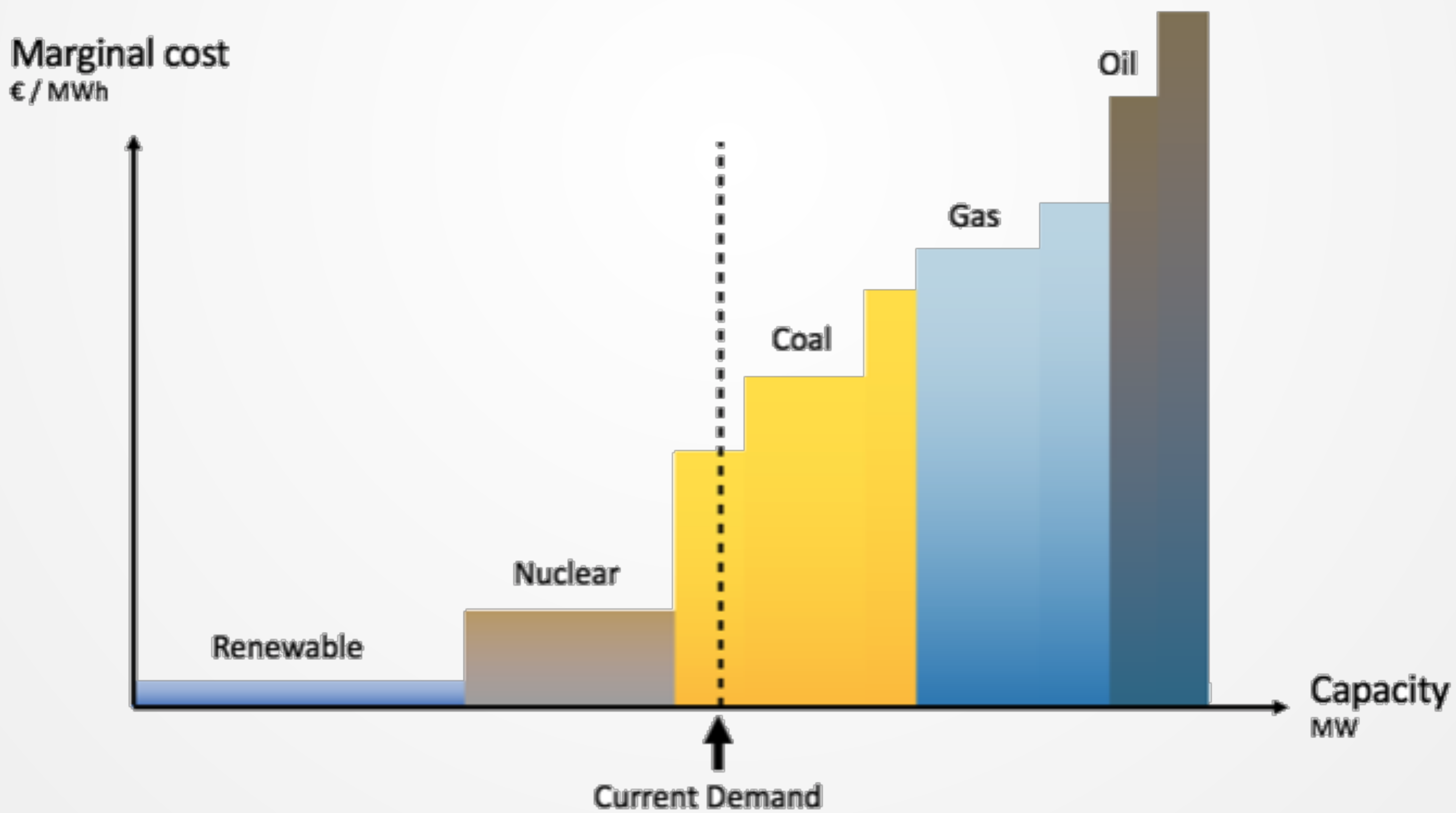
The Marginal origin of electricity!

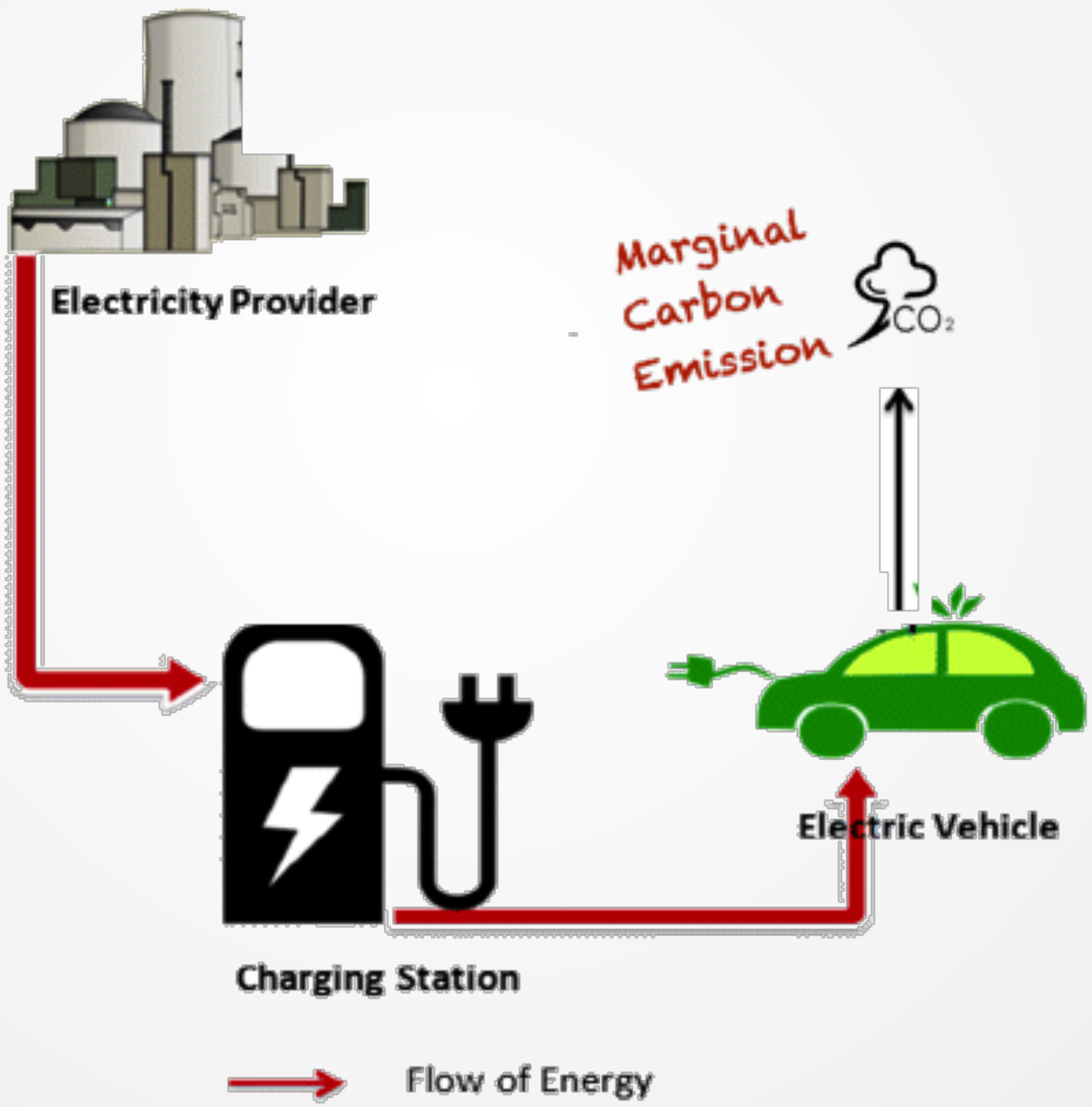
- The marginal power plants can react quickly to changes in electricity demand (e.g.gas turbine),
- Cannot be a wind turbine or solar cells,
- Generation systems are called upon in a specific order of increasing cost



The “merit order curve” [Corradi (2018)]

The marginal carbon emissions!

- The quantity should guide our choice as a flexible consumers,
- When is better to charge?
- What kind of generation would be marginal at a given time?



Example: Electric vehicle charging

The Marginal Emission Factor: Definition

- The metric that estimates the CO_2 intensity of a demand change
  - A function of the specific CO_2 intensity of the individual generators that respond to that change
- The change in CO_2 emissions relates to a unit change in electricity demand,
  - Assumed to be no structural change in the electricity system being analysed (i.e. no power station commissioning or decommissioning, no fuel price changes, etc.).
- Gain valuable insights into how our electricity consumption choices impact CO_2 emission.

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The Marginal Emission Factor: Interest

- Crucial for performance assessment
  - Leads to decisions regarding the relative merits of CO2 reduction strategies.

- Indicates which interventions are the most potent in terms of climate change mitigation.

- Some Common situations
  - Comparing what times are best to use or store energy
  - Comparing where is best to site a new energy asset.
  - Evaluating electrification.
  - Evaluating low-emissions energy sources
  - Design policy

Outline

1. Motivation ✔
2. Proposed Methodology
3. Fundamental model
4. Statistical models
5. Estimation results
6. Conclusion

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Proposed models for MEF estimation

Real System

Marginal Emission Factors are unobservable

Fundamental Models

Merit Order Model

- Hourly MEF by ordering the power plants incrementally based on their marginal costs and including an additional unit of demand.
- Methodology is static!

Energy System Model (ESM)

- Hourly MEF by computing the model with one additional unit of demand.
- Emulate energy market principles and dynamics.
- Methodology is time intensive

Statistical model

- Less complex approach
- Linear regression model
- MEF is the slope of the regression line (in average).

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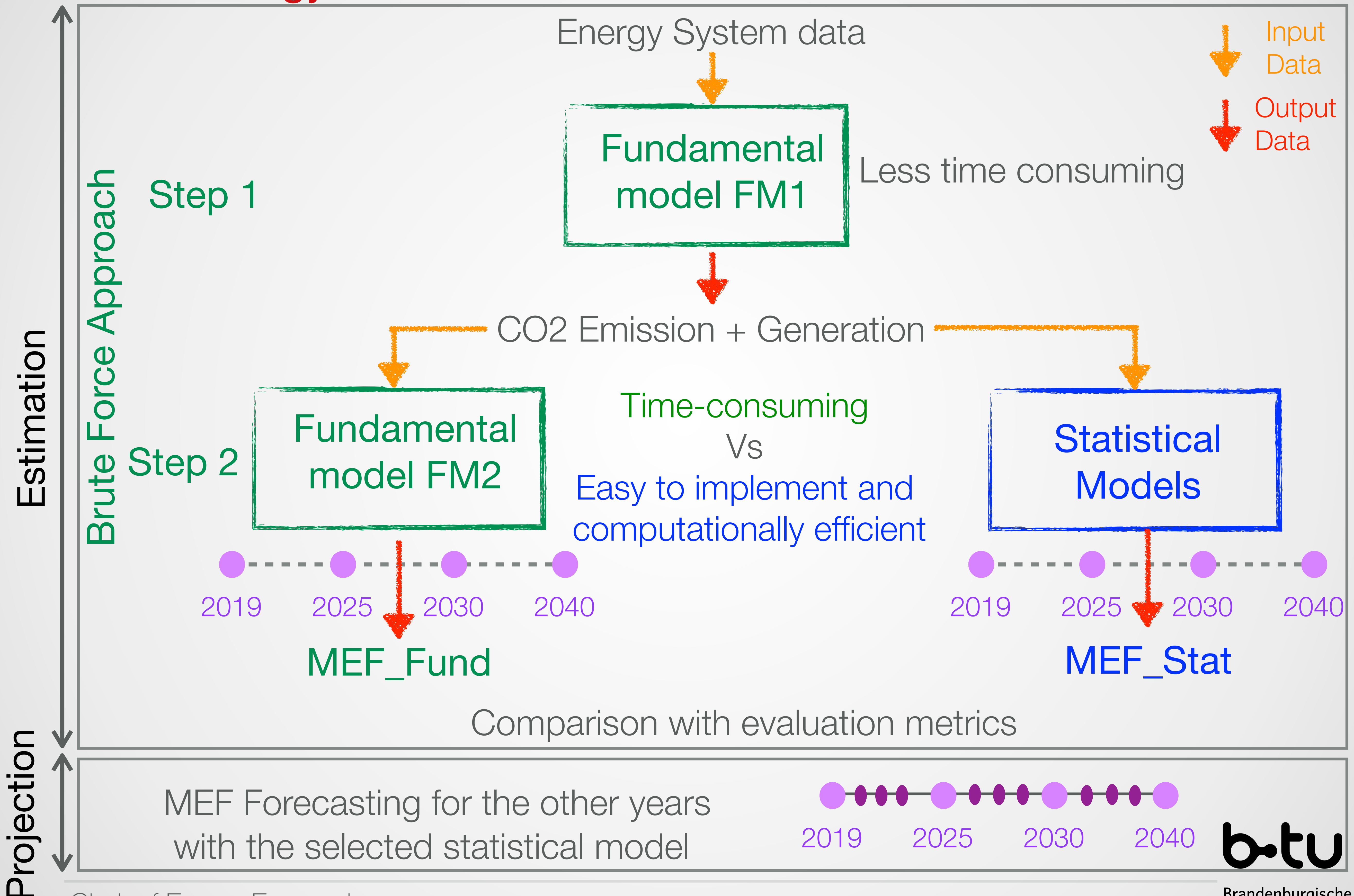
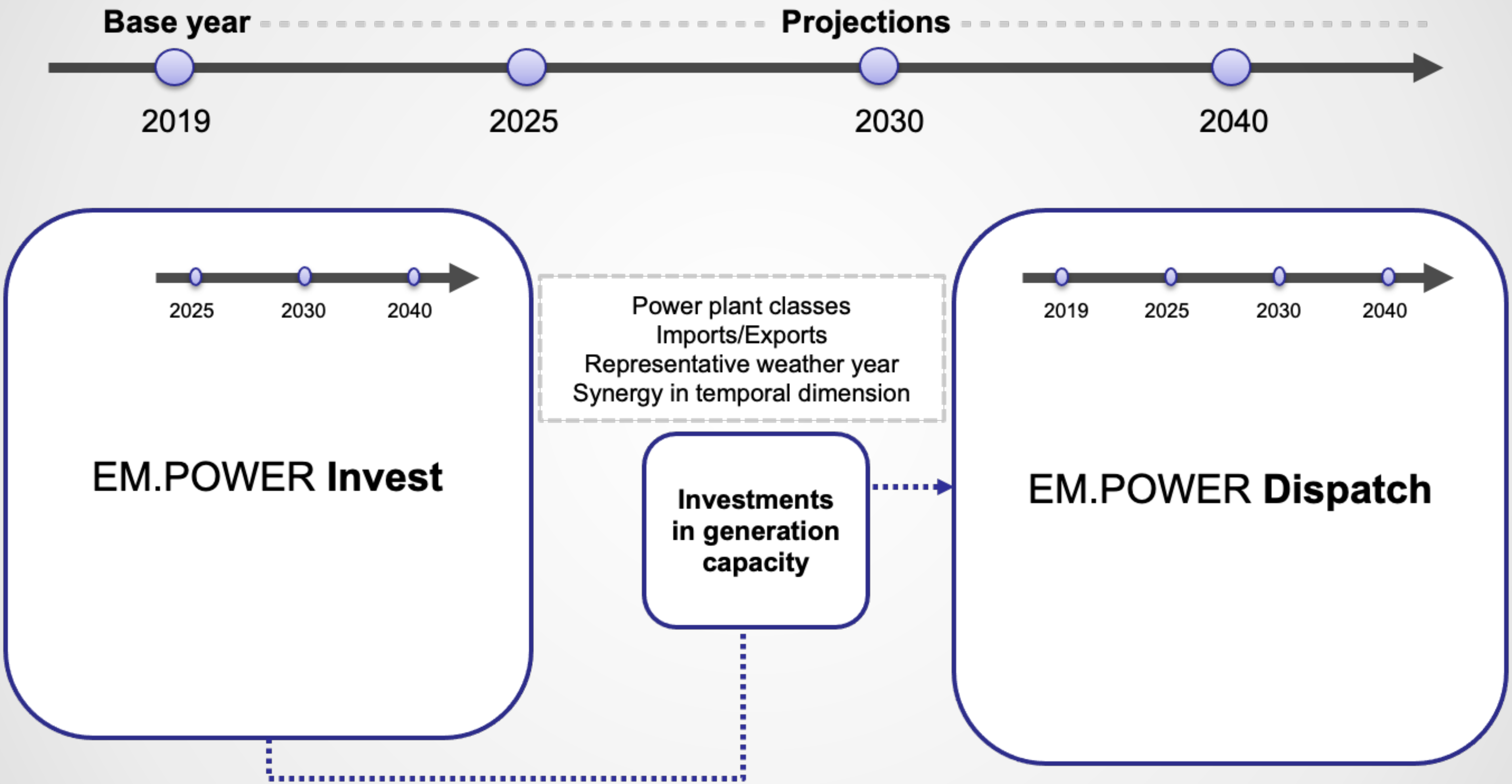
Methodology



Coupling Energy System Models



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Proposed model for MEF estimation

- Hawkes (2010, 2014), Seckinger & Radgen (2021), Huber et al. (2021)
- Simple linear regression

$$\Delta E_t = \beta_1 \Delta G_t + \varepsilon_t$$

Where

ΔE_t: measures the difference in emissions between two consecutive hours,

ΔG_t: measures the difference in the generation at a time t

β_1: The marginal emission factor

ε_t: the error term

Proposed model for MEF estimation

Smooth Transition Regression Model (LSTR)

- Regime-switching through a nonlinear regression model
- Allows the electricity generation process to switch between normal and high-regimes to capture the structural changes

The STR model

$$\Delta E_t = \phi z_t + \theta z_t T\left(\gamma, c, s_t\right) + \varepsilon_t$$

- ΔE_t is the dependent variable
- z_t is a vector of exogenous variables, $z_t = \left(\Delta G_t\right)$
- ϕ_t is a parameter vector of the linear part,
- θ_t is a parameter vector of the nonlinear part,
- ε_t is an independently and identically distributed noise, $\varepsilon_t \sim \mathrm{i,i.d,}\left(0,\sigma^2\right)$

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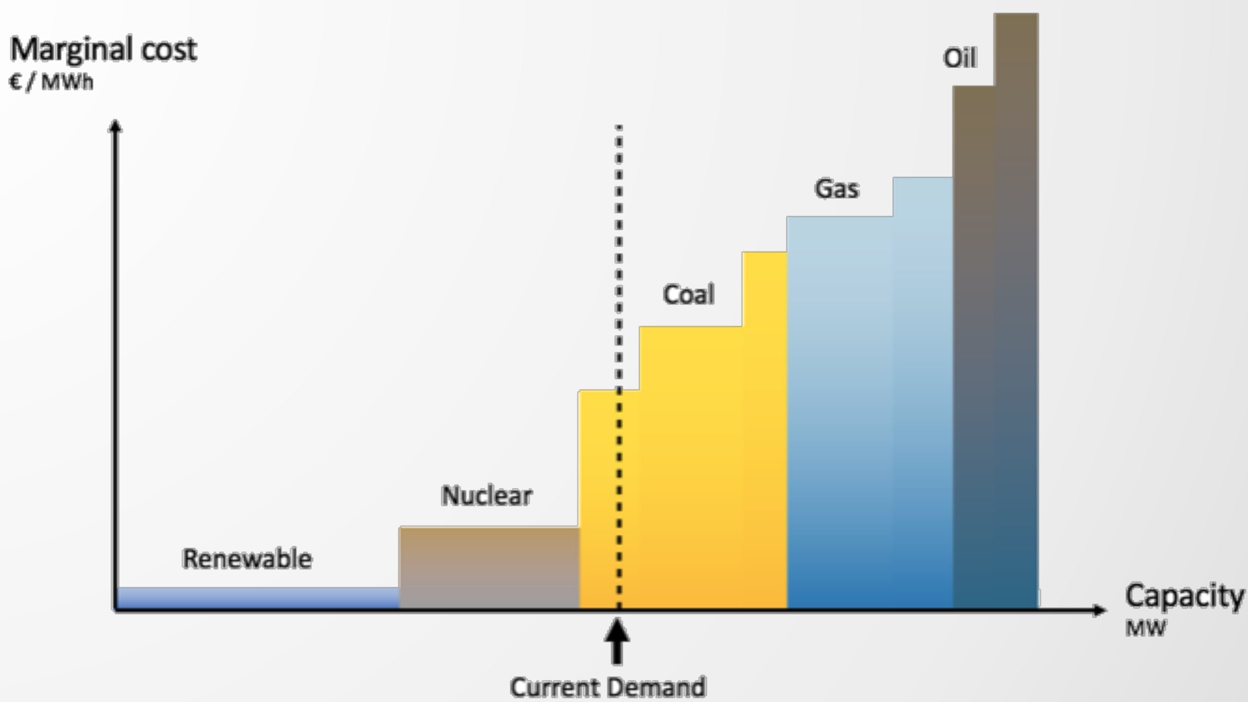
Smooth Transition Regression Model (LSTR)

- The Transition function: logistic function

$$T(\gamma, c, s_t) = \left(1 + \exp\left\{-\gamma\left(s_t - c\right)\right\}\right)^{-1} \qquad \gamma > 1$$

- Depends on the transitional variable s_t, the slope parameter γ, and the vector of location parameters c.
- Larger values of γ are associated with more rapid transitions.
- The parameters are optimized using ridge regression to prevent overfitting.



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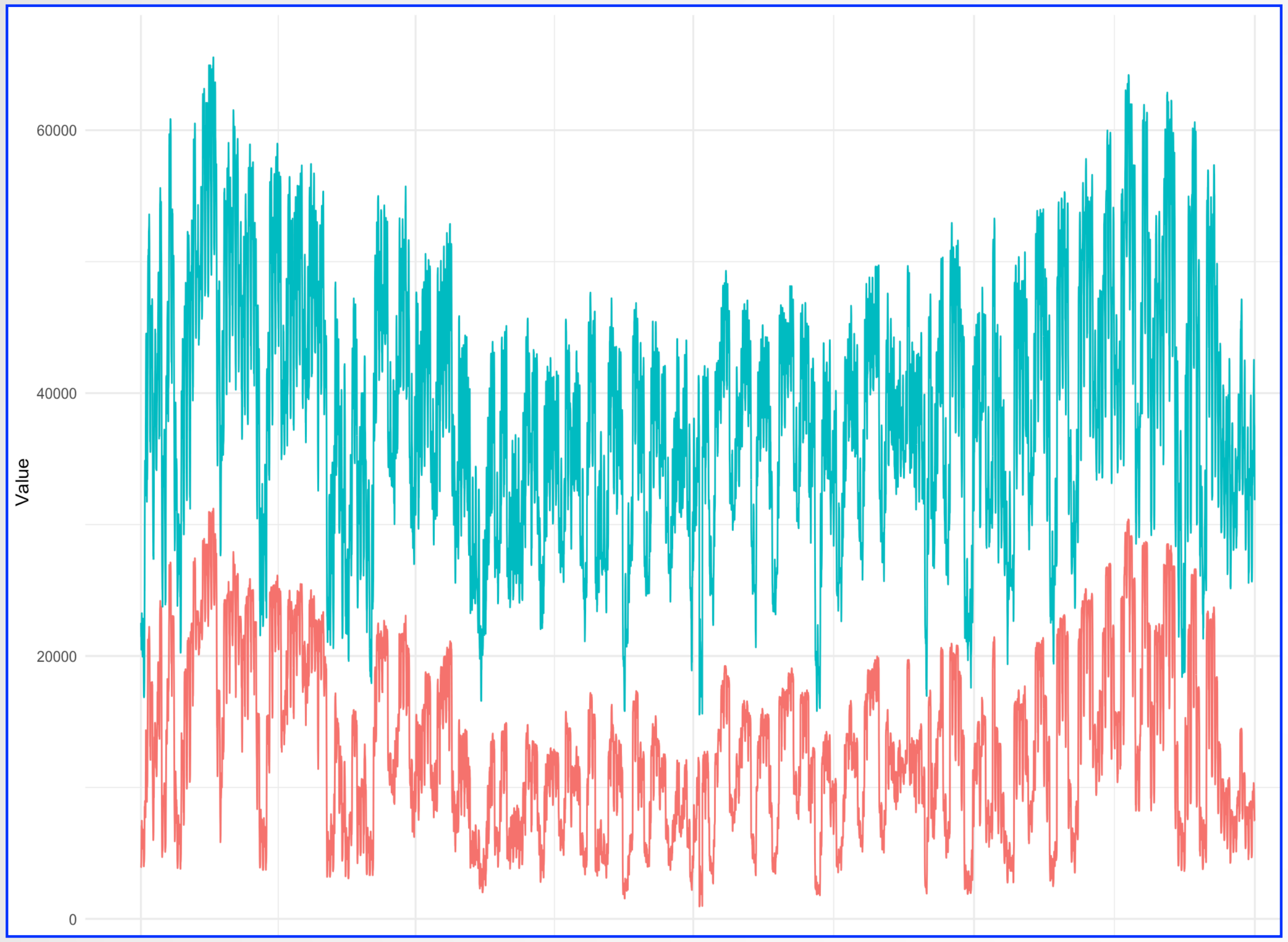
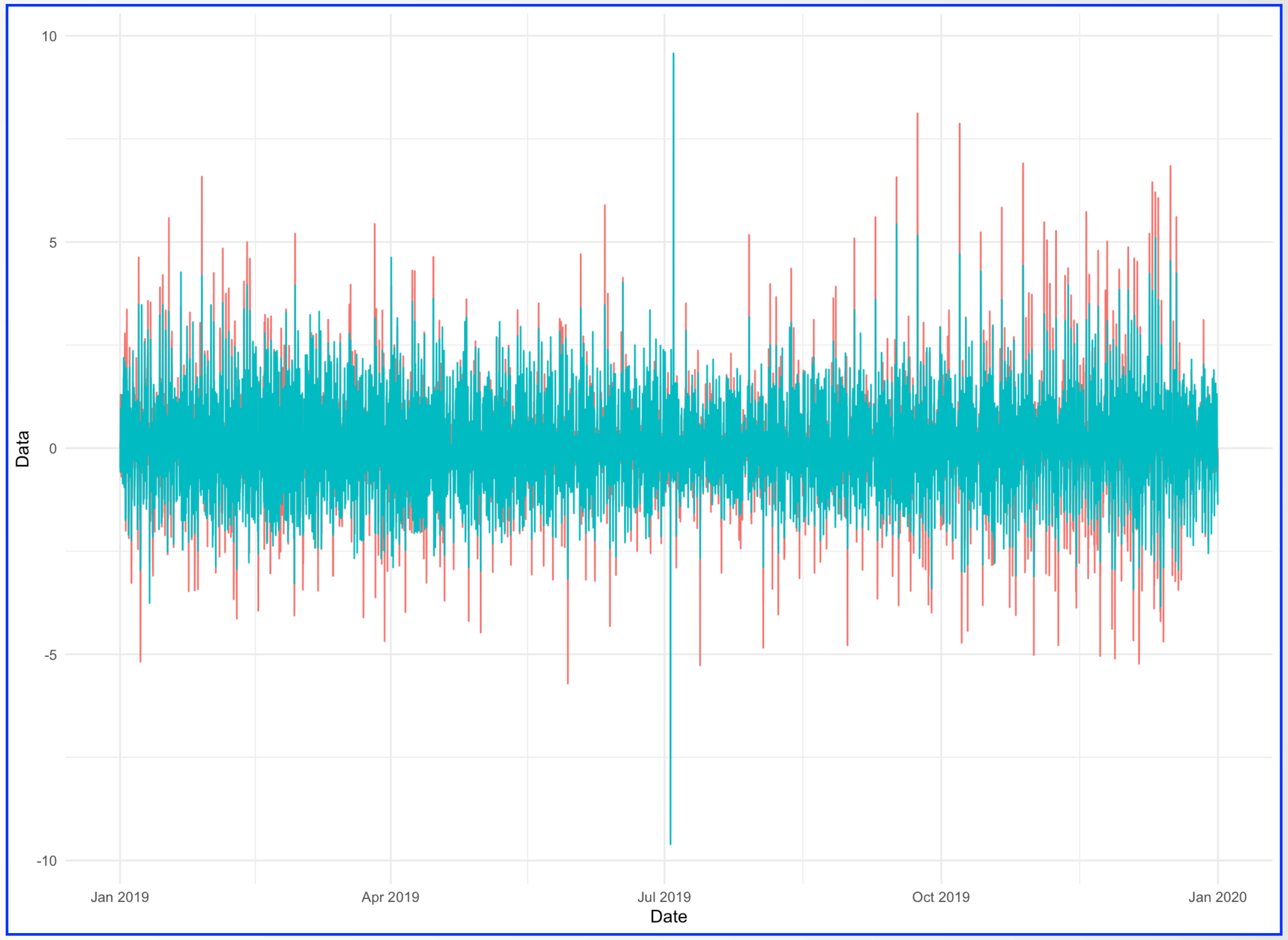
Statistical model input data:



(a)



(b)

CO2 Emission and Generation (a) data and their variations (b) in 2019

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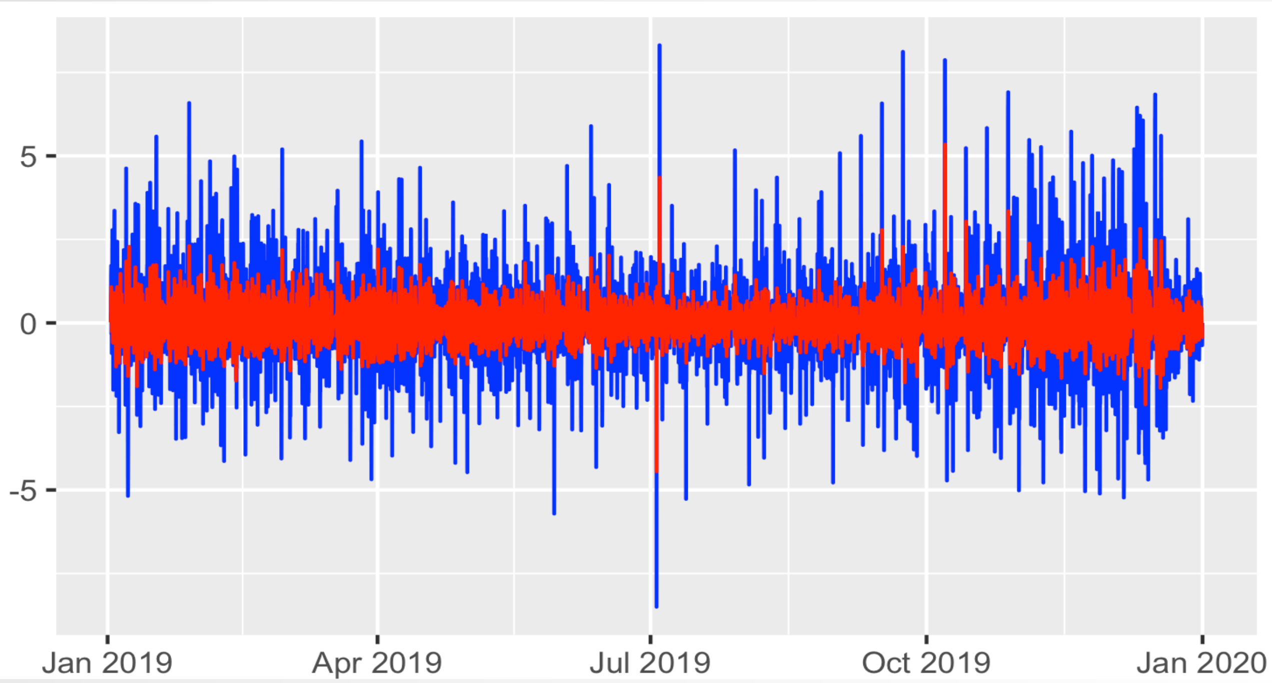
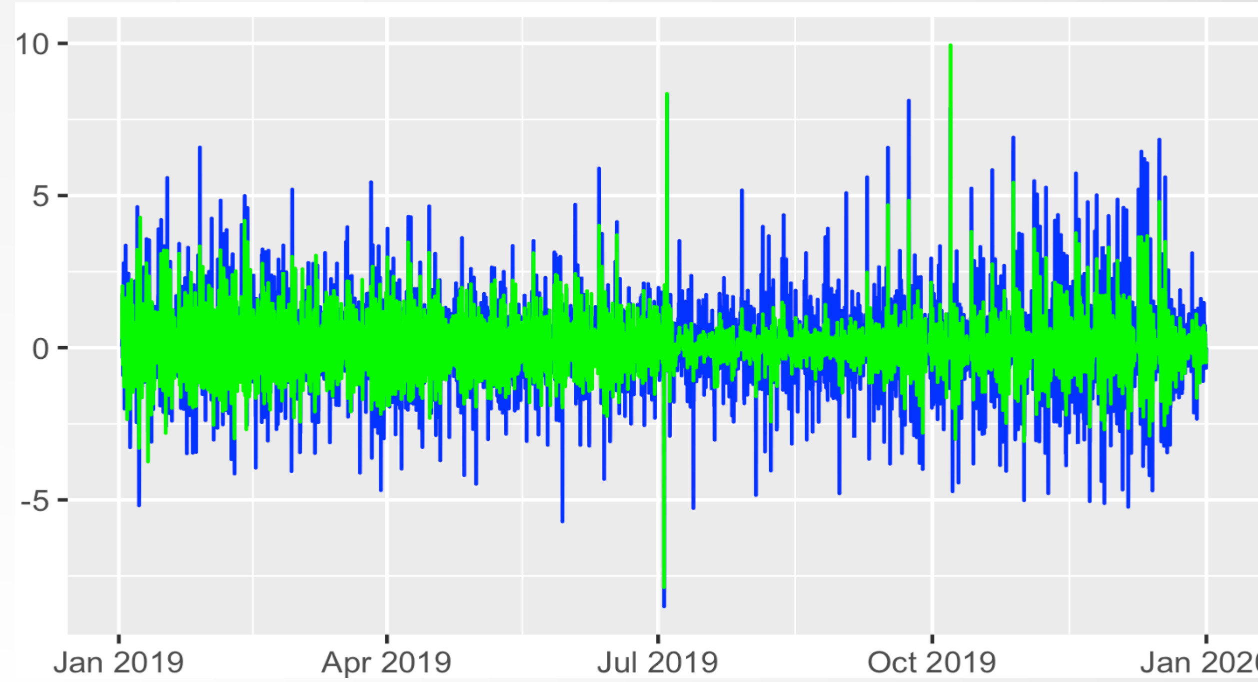
Statistical model input data:



(a)



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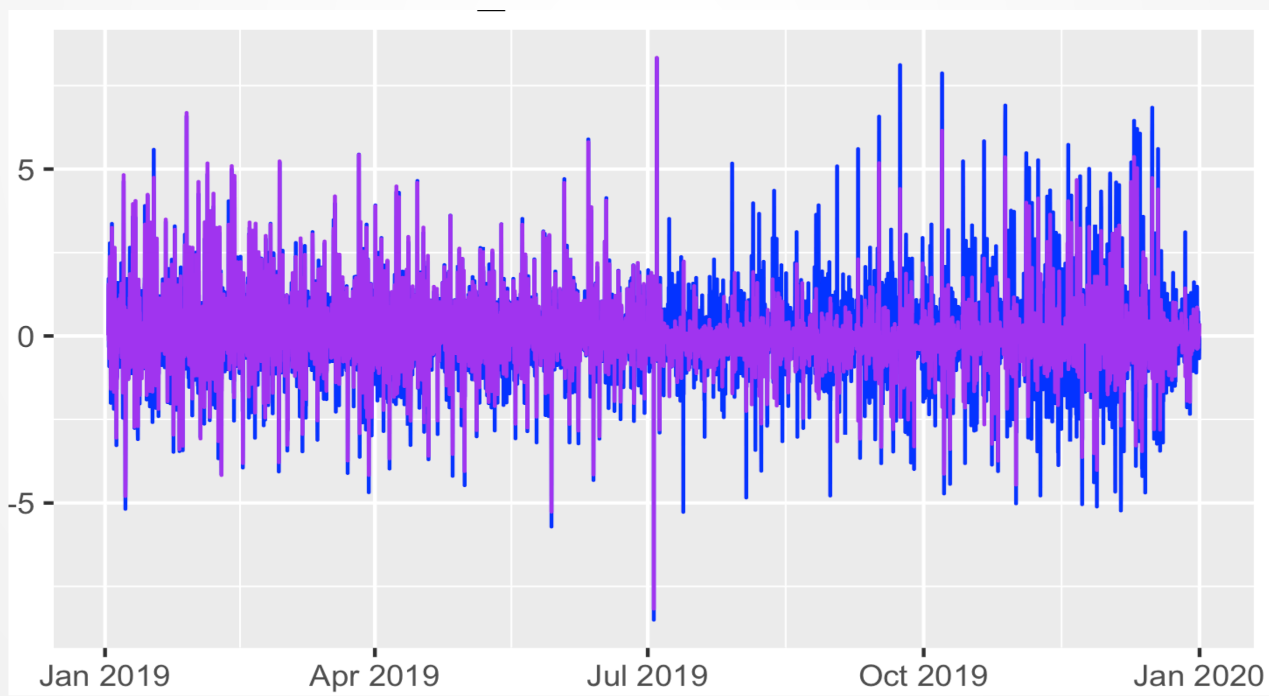


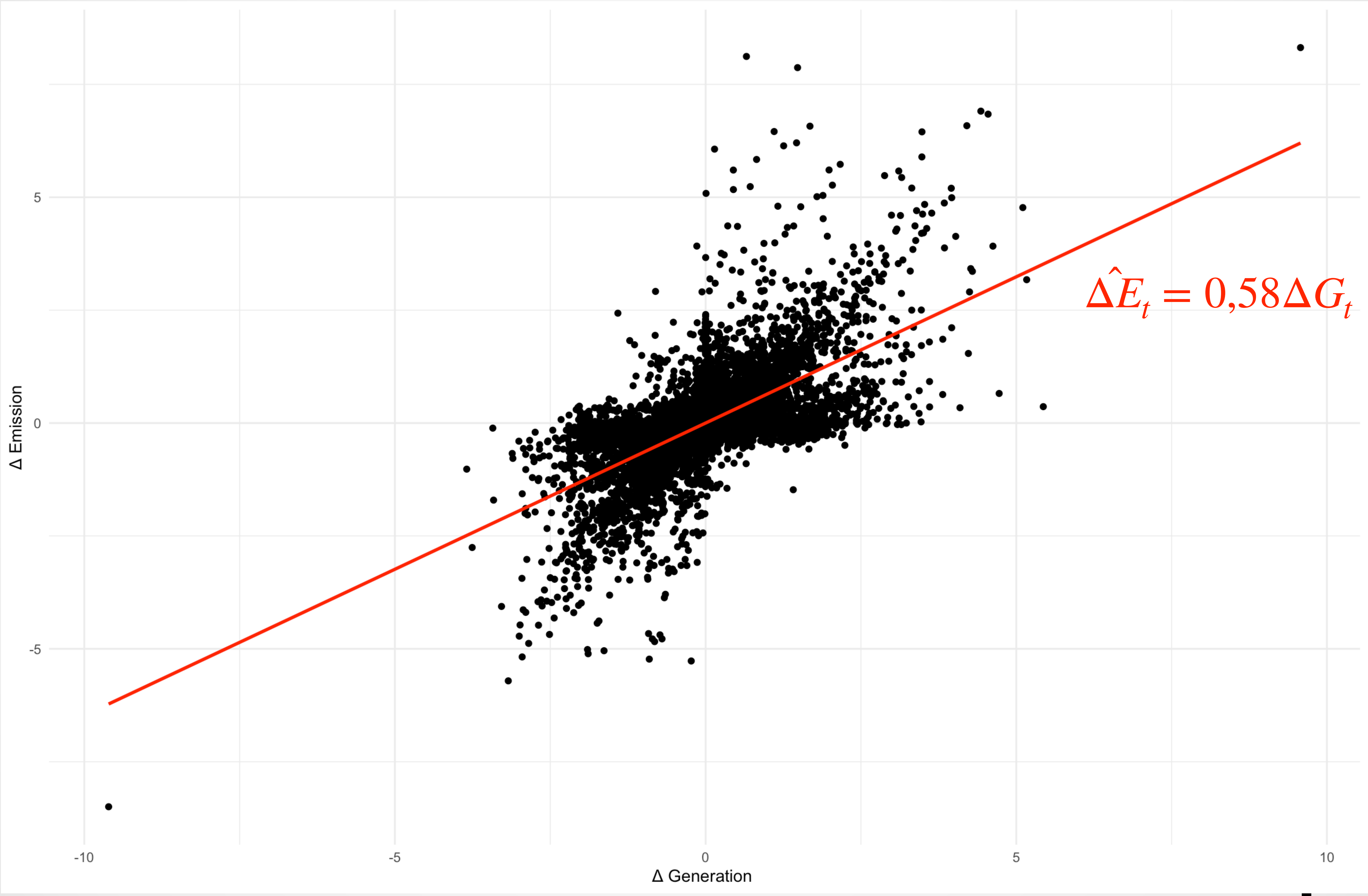
(c)

Emission_Actual, Emission_OLS, Emission_Kalman, and Emission_LSTR

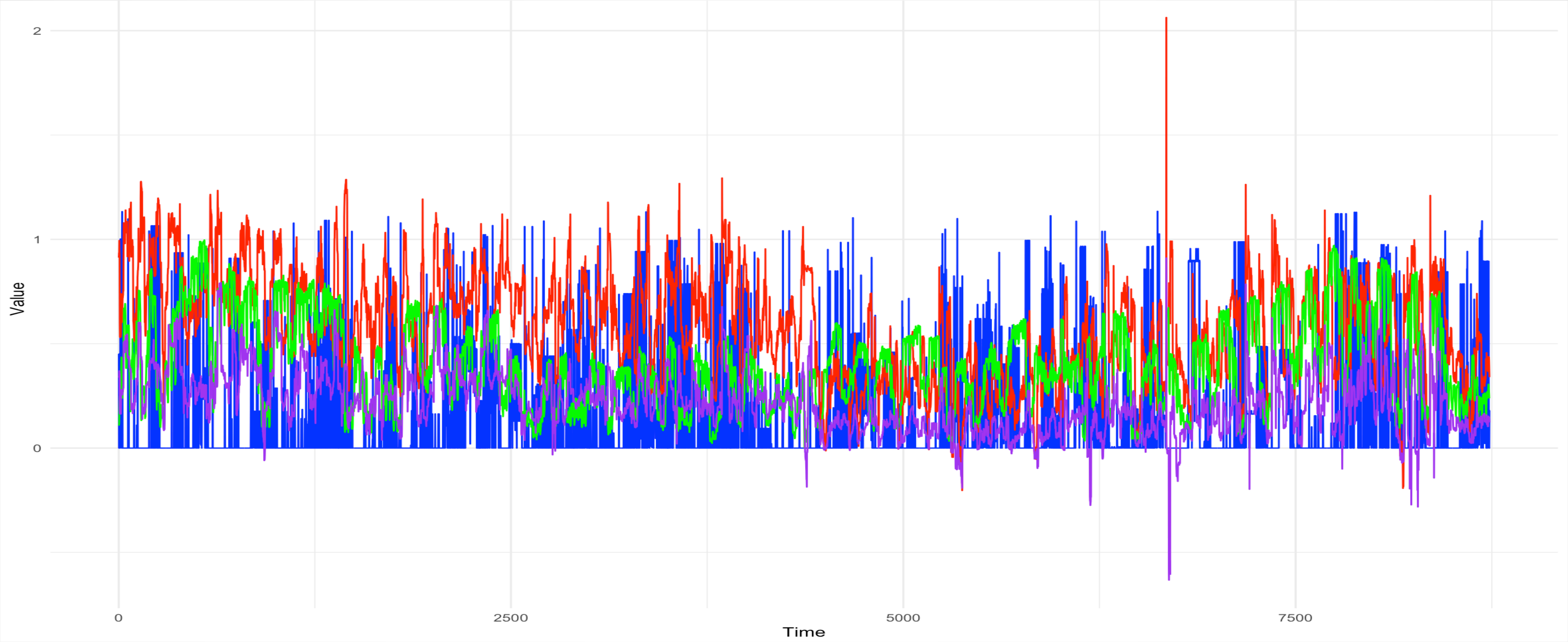
Statistical model Estimation results:

Model	MSE	MAE	RMSE
Linear Regression	0,633	0,491	0,795
Smooth Transition Regression Model	**0,344**	**0,353**	**0,587**
Kalman filter regression	0,513	0,429	0,683

Linear regression model



Estimated MEFs



MEF_Fund, MEF_OLS, MEF_Kalman, and MEF_LSTR time series in 2019

Model	MEF_Fund	MEF_OLS	MEF_Kalman	MEF_LSTR
Average	0,15	0,58	0,40	0,22

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Evaluation Results

Model	MSE	MAE	RMSE
MEF_Linear Regression	0,320	0,495	0,566
MEF_Smooth Transition Regression Model	**0,093**	**0,243**	**0,305**
MEF_Kalman filter regression	0,174	0,354	0,418

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Conclusion

- Hourly historical data for MEF is not available.
- Estimating MEF through a fundamental model is the most accurate existing methodology.
- The fundamental approach to estimate MEF is complex, serves as the benchmark.
- Statistical models offer a less complex alternative.
- The LSTR model shows the lowest evaluation metrics.
- Therefore, the LSTR model will be adopted to estimate the MEF, especially when short-term MEF estimation is needed.
- We can confidently rely on the LSTR model and make informed decisions for sustainable energy practices based on its estimations.

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Thank you for your attention

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