Modelling Energy Transition in the Netherlands

Data Collection and Preparation

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1 METHODOLOGY

The energy sector, considered to be a complex system, is characterized by non-linear dynamic relations and feedback loops. This constitutes a reason why its behavior is not easily prognosticated in advance. However, the prediction of the system performance and its side effects is required in order to regulate the decisions that define it.

In order to explore the system behavior, answer the research question, identify and comprehend the different scenarios of achieving or directing the energy transition in the Netherlands, a model is created. During this project, a system dynamics model that depicts the energy sector in the Netherlands is developed based on publicly available time-series data.

System dynamics simulation models provide a promising instrument to support decision making. The (potential) contribution of the model created relies on the following aspects:

- Identifying patterns among the system's components.
- Understanding dynamic system behaviours and the structures that generate them.
- Exploring paths into the future.
- Assessing different strategies and directing the energy transition in the Netherlands.

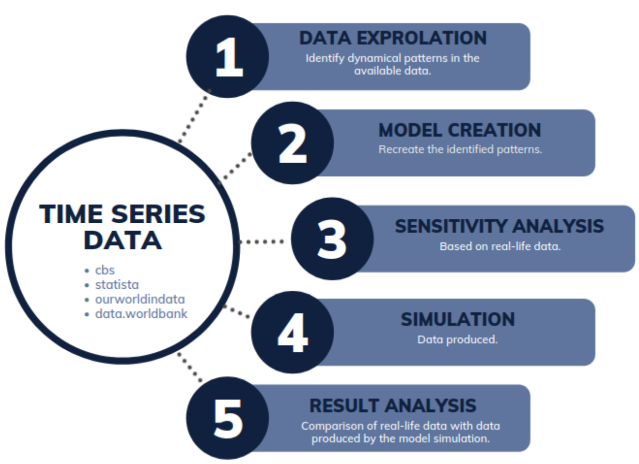

Figure 1: Overview of data flow

Overview of the process. Firstly the necessary data is gathered and analysed. The model is created based on the dynamical patterns that are identified within the data. Then, the model is subject to sensitivity analysis, based on real-life data in order to fine tune it. After the sensitivity analysis, the model is simulated and data are produced. Finally, the produced data are analysed and compared to real-life data available. In this way the validity of the model can be assessed. The overview of the process is illustrated in figure 1.

1.1 Data Collection

Most of the data used for the development and validation of the model is already collected by the dutch Central Bureau for Statistics (CBS)[1]. The CBS provides a branch with datasets on the energy sector. The data provided are time-series since they form a collection of the observations gathered through repeated measurements over time. The CBS also has a department that focuses primarily in Renewable energy; consumption by energy source, technology and application. The available data date from 1990 until 2022 and is broken down into energy source/technique and into energy application (electricity, heat, transport). In addition there is data available on Renewable electricity; production and capacity, dating from 1990-2022. The data is broken down according to the type of energy source and the technique used to obtain the electricity. A distinction is made between four main categories: hydro power, wind energy, solar power and biomass. However, the available data are not gathered for the purpose of this specific project, therefore it is important that this data is critically analysed before it is used in the model. In the appendix figures are attached that present the CBS datasets and provide useful insight into the Dutch energy sector over time.

During the data exploration it became evident that not all the data that are required for the development and validation of the model are available in CBS. Those data are collected from various other sources such as Statista [2], Our World in Data [3] and the World Bank [4]. Data related to the CO2 production (annual, per capita) per fuel type (coal, oil, gas, other sources) is gathered from Statista and The World Bank, available from 1960. Data on the electric power consumption is provided by The World Bank and dates back to 1960. Finally, data on the different renewable energy sources capacity is provided by Statista.

[1]CBS
[2]Statista
[3]Our World in Data
[4]World Bank Group

1.2 Data Analysis

The data is used to identify the dynamical patterns the model is required to be able to recreate. Additionally, data can provide the bounds to the parameters and form the the range of their inputs/ outputs during the sensitivity analysis of the model.

In order to create an accurate model, all its components should be based on data. The variables included in the first version of the stock and flow diagram are listed in table 1.

Table 1: Stock & Flow Diagram - Variable List

Variable name	Type	Measurement Unit
Adjustment factor	Constant	
Approved %	Auxiliary	%
Capacity bankruptcy	Auxiliary	GWh/year
Capacity lifespan	Constant	year
Capacity bankruptcy lifespan	Constant	GWh/year
Capacity retirement	Auxiliary	GWh/year
Capacity under construction	Level	GWh
Capital expenditure rate	Auxiliary	$/year
Capex costs	Constant	$/year
Construction delay	Constant	year
Depreciation rate	Auxiliary	$/year
Desired new capacity addition	Auxiliary	GWh/year
Energy demand per citizen	Constant	GWh
Energy production capacity	Level	GWh
Energy security	Auxiliary	%
crude birth rate	Constant	
Gross demand	Auxiliary	GWh
Investment	Level	$/year
"Min % to invest"	Constant	%
"Net profit."	Auxiliary	GWh/year
New capacity orders rate	Auxiliary	GWh/year
"New capacity start-up rate"	Auxiliary	GWh/year
Population	Level	
ROIC	Auxiliary	%
Total available resources	Auxiliary	
Total supply	Auxiliary	GWh/year
Total supply cost	Auxiliary	$/year
Wholesale price	Auxiliary	$/year

The initial values of the constant and level variables are listed in table 2.

1.3 Model Development

The main aim of this thesis is the construction of a generic model that depicts the dynamics within the energy sector and the impact of different scenarios; in this case different ways to achieve the energy transition. The appropriate modeling approach to use depends on the assumptions about the stocks and flows in the system that are applicable to a specific purpose. During this case study two different types of models will be used. The system modeling will be firstly approached by a causal loop diagram and then by a stock and flow diagram. The first version of the stock and flow diagram that corresponds to each energy source (renewable, non-renewable) is illustrated in figure 2.

Table 2: Stock & Flow Diagram - Initial Value

Variable name	Inital value
Adjustment factor	1.4
Capacity lifespan	25
Capacity bankruptcy lifespan	100
Capacity under construction	8
Capex costs	1600000
Construction delay	1
Energy demand per citizen	0.047972222
Energy production capacity	0.011508
crude birth rate	9.7/1000
"Min % to invest"	10
Population	17340000

The diagrams that are going to be constructed will be grounded on the available data. In particular, after the analysis of the data the patterns among the various elements of the sector are going to be identified. The relations and feedback loops within the models are going to be established based on the patterns identified. Therefore, the models are going to depict the interconnections among the available data.

The equations that correspond to the variables of the first version of the stock and flow diagram are listed in table 3. The first model was focused on wind power. The same model can be used for the rest energy sources available with the appropriate adjustments on the variables' values and equations.

1.4 Sensitivity Analysis

The development of a basic model does not recreate the precise behavior of the system presented. The stock and flow diagram that is created includes equations that determine the value of its elements. The equations of the basic model only depict the relations among the various components of the system and do not provide realistic results.

In order to fine tune the model and produce accurate results a sensitivity analysis will be conducted. During this process, the available data are going to be analysed meticulously in order to determine the equations that can recreate the actual behavior of the system. The sensitivity analysis of the model will propose and evaluate different scenarios that outline the direction and speed of the energy transition.

The stock and flow diagram presented in figure 2 currently produces results that do not reflect the system's actual behavior. Therefore, sensitivity analysis should be conducted in order to achieve the finalisation of the model with the appropriate behavior.

1.5 Model Simulation

The mathematical model produced by this thesis has a predictive function since the initial objective is to use the simulated model to guide the energy transition. The simulation constitutes an experiment that is performed on a model with the objective to generate insight that enhances the understanding of the behaviour of the system. The change of the conditions (the experimental frame) enables the analysis of the system for different scenario's. The simulation

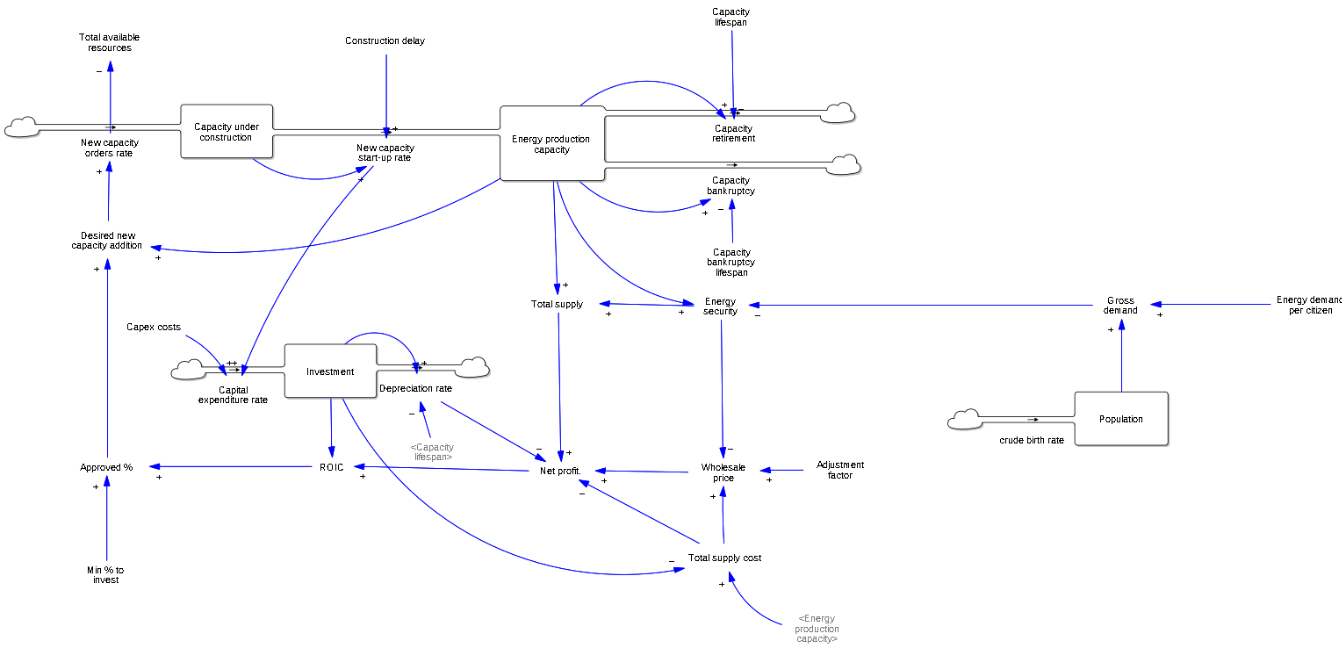

Figure 2: Stock & Flow Diagram - Energy Source

Table 3: Stock & Flow Diagram - Variable Value

Variable name	Variable value
Approved %	ROIC - "Min % to invest"
Capacity bankruptcy	Energy production capacity*Capacity bankruptcy lifespan/100
Capacity retirement	Energy production capacity/Capacity lifespan
Capacity under construction	New capacity orders rate-"New capacity start-up rate"
Capital expenditure rate	Capex costs*"New capacity start-up rate"
Depreciation rate	Investment/25
Desired new capacity addition	max (0,Energy production capacity * "Approved %"/100)
Energy production capacity	"New capacity start-up rate"-Capacity bankruptcy-Capacity retirement
Energy security	Energy production capacity/Gross demand
crude birth rate	crude birth rate per thousand of people
Gross demand	Energy demand per citizen*Population
Investment	(Capital expenditure rate-Depreciation rate)*Investment
"Net profit."	(Total supply*Wholesale price)-(Depreciation rate*Total supply cost)
New capacity orders rate	Desired new capacity addition
"New capacity start-up rate"	Capacity under construction/Construction delay
Population	crude birth rate*Population
ROIC	Net profit/Investment*100
Total available resources	1-"New capacity start-up rate"
Total supply	Energy production capacity*Energy security
Total supply cost	Energy production capacity/ Investment
Wholesale price	Adjustment factor*Total supply cost/Energy security

of the model produces data that is later analysed. Mainly, growth and saturation rates of different points of the system are going to be examined.

The model is going to be calibrated in order to quantify the relationships among its elements and explore its projection into the future. In this way, insight on the parameters that fulfil the requirements of the Paris Agreement will be provided.

1.6 Model Evaluation

One of the last stages of the research is the evaluation of the results that it has produced. The real life data that will be used during the calibration of the model can be also used to show that the data produced by the model is valid. Therefore, the comparison of the data produced with the real life, available data is going to form the main evaluation method of this thesis. However, the model might have limited accuracy due to its limitations.

APPENDIX

Figure 3 shows the supply, transformation and the consumption of energy in a balance sheet. The data are available from 1946.

Figure 4 expresses the use of renewable energy as gross final consumption of energy in the Netherlands. The figures are broken down into energy source/technique and into energy application (electricity, heat and transport). The data are available from 1990.

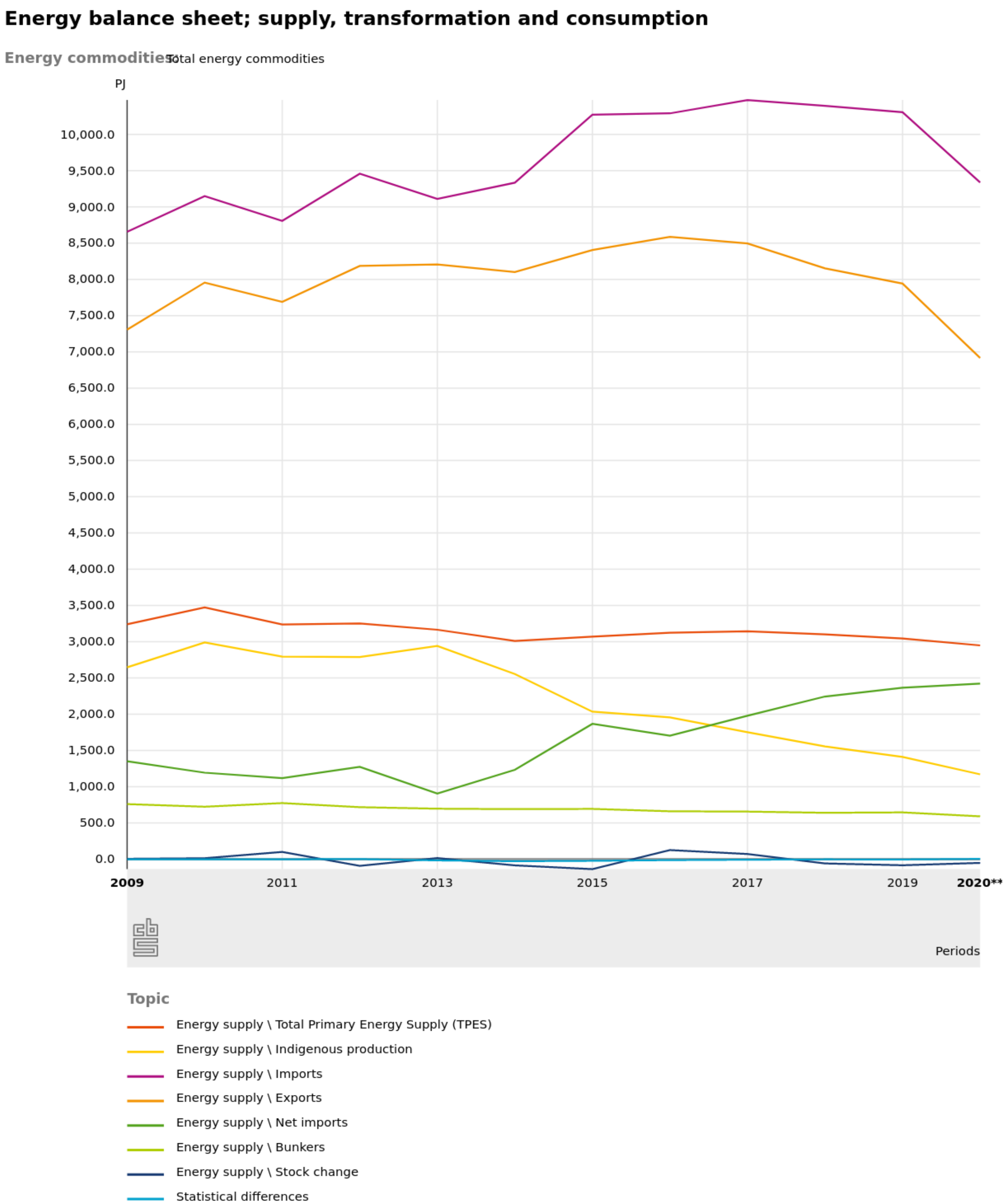

Figure 3: Energy balance sheet; supply, transformation and consumption

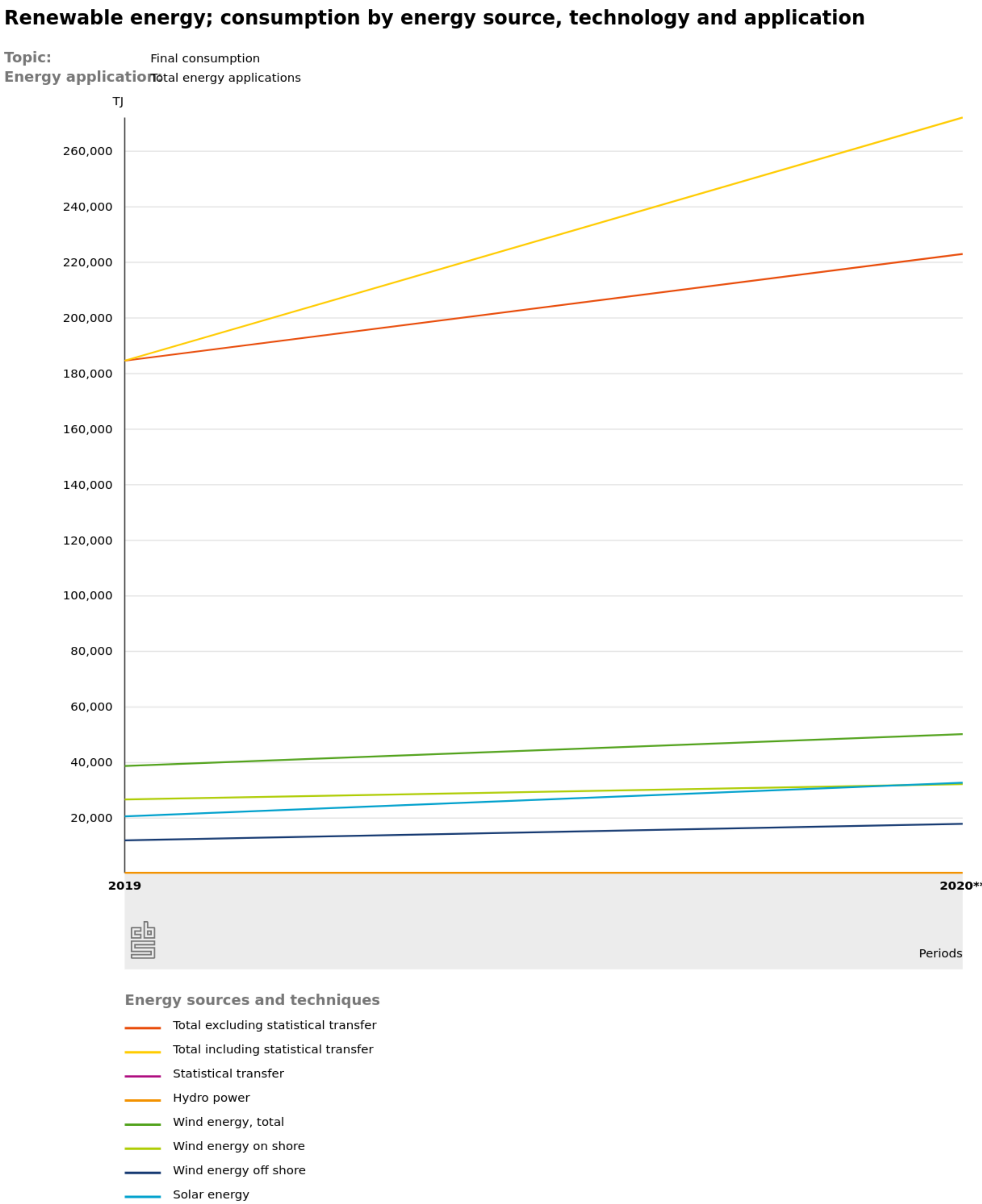

Figure 4: Renewable energy; consumption by energy source, technology and application