Modelling Energy Transition in the Netherlands

Thesis Design

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ABSTRACT

Avoiding the uncontrollable climate change requires the design and implementation of the appropriate interventions. This constitutes a complex challenge for policymakers of different levels of governance. The energy sector is a dynamic and complex system with various constituent components and complex interactions among them. Hence, its development requires approaches that are able to adapt to its dynamic complexity. This research proposes a system dynamics approach to design and construct an integrated model that simulates the energy transition in the Netherlands, at a country level. The energy sector of the Netherlands is used as a case study, however, the model can be applied in other context with the appropriate alterations. This research will combine a literature study, the analysis of available data, the creation and evaluation of a simple initial model to simulate the energy transition in the Netherlands. This thesis will be part of a new research area at the Institute for Advanced Study (IAS) [1] and the University of Amsterdam (UvA) [2].

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KEYWORDS

modelling systems dynamics; energy modelling; energy transition; renewable energy systems; energy policy; CO2 emissions

1 INTRODUCTION

Energy is fundamental for the existence and the development of countries. Thus, the provision of energy that is secure, affordable, clean, environmentally-friendly, produced and used efficiently is essential for sustainable development. The Netherlands is aiming for a rapid transition due to the urgent need to avoid the uncontrollable climate change and the fast increasing energy demand. The decline of the fossil energy resources, the growth of the world's population and the need to fulfil the requirements of the Paris Agreement makes the need for a sustainable energy sector more important. Consequently, concerns such as the growth of energy demands, the threats of carbon dioxide (CO_2) emissions and the constrains of the use of fossil fuels unite researchers of diverse fields, governments and decision makers in order to design and develop their energy policies in a sustainable way.

The formulation of a sustainable energy sector approaches a multi-level problem that interacts with many socio-economic and political interests. The system consists of diverse supply sources, multiple stakeholder involvement with different interests and can be regulated by external and internal factors. All the aforementioned mean that the energy sector constitutes a dynamically complex system with various components and their interactions, since it is not rooted in one discipline. The energy system ought to meet energy needs, complement the national economy of each country, enact environmental sustainability and mitigate social inequalities.

In order to achieve the energy transition in a sustainable manner a comprehensive understanding and analysis of the energy sector's components and the interactions among them is required. The energy transition in the Netherlands is concerned with cornerstone alterations in the existing systems of production, provision and consumption of energy. Currently, the ability to understand how the system works and predict possible interventions in order to provide leverages that help the transition is limited.

1.1 Research Question

This thesis will adopt a systems dynamic approach to construct a conceptual model for examining the performance of the energy sector in the Netherlands, as a case study. The model explores an integrated system's approach towards assessing and implementing the energy transition. In addition, it identifies feedback mechanisms likely to influence the behaviour of the sector. In order to achieve this, the following research question is formulated:

> What dynamics result from the distinct influences in the Dutch energy system and how can the energy transition towards sustainability be realised while taking into account the many boundary conditions that apply, as well as the social, economical and ecological aspects?

To facilitate the investigation, we populate intermediate goals underneath this overarching research question which we formulate as follows:

(1) What dynamical patterns can be observed in the data available particularly in the Netherlands?

(2) What changes to the existing models are required to capture the patterns in the data and describe the energy transition in the Netherlands?

[1] Institute for Advanced Study (IAS)
[2] University of Amsterdam (UvA)

(3) Keeping the recent trends, can the Netherlands fulfil the requirements of the Paris agreement? What are the reasons?

At the time of writing this thesis design, the exact specifications of the research process are not yet determined and will be further specified according to the future findings.

2 RELATED WORK

In this section, a brief background on the related literature is presented. The section provides an overview of the Dutch energy transition as well as the background of the formulation of a simulation model.

2.1 Background

The energy sector faces serious problems [10]. Limits to growth are fast approaching for various reasons such as the excessive fossil fuel extraction, high emissions and high energy dependency [2]. Consequently, avoiding the effects of global warming, broadening human well-being, security while adopting a sustainable development are becoming more and more urgent. The transitions towards a more sustainable energy system are considered to be helpful.

Therefore, much interest has been shown in energy transition from policy makers, governments and academics, due to the big improvements it achieves in the environmental efficiency [9]. Many approaches have been developed in order to investigate the ongoing energy transition [4]. The distinct approaches focus on different aspects that influence the energy transition. However, many of those approaches have been disapproved due to their limited incorporation and representation of societal factors and socio-political dynamics [6].

In the context of energy transition, various emerging renewable energy initiatives are introduced in the Netherlands, as well as in other countries [7]. However, it is not made clear whether they make a difference in the influence, direction and speed of the energy transition. Therefore, the decision on the energy policies to form and adopt is ambiguous. In addition, during the past couple decades remarkable advances have been achieved in comprehending the dynamics of deeply interconnected systems, such as the energy sector.

2.2 Formulation of a Simulation Model

Energy system modelling is used for supporting energy policy while creating and evaluating distinct energy transition approaches [3]. There is a wide, continuously expanding variety of energy models and many studies that focus on the investigation of the energy sector from specific scope. For instance, Keller, organises the models in three different types [1] depending on their functionalities:

(1) Models constructed on proven theories and mathematical abstractions of a real-world target framework.

(2) Models that calculate the responses in hypothetical questions and provide an output (data). The simulations represent the behavior of an actual system that is computed by a set of equations based on theoretical observations. However, the empirically verification of those results is not feasible.

(3) Models that reproduce the performance of entities.

The model that is going to be created during this research is going to be based on the model designed in Laimon et al. [5]. The Laimon et al model depicts the development of the energy sector in Australia. The appropriate adjustments need to be integrated in the model that is going to be created in order to illustrate the Dutch energy sector.

3 METHODS

The problem statement, literature review and subsequent research question illustrate that the energy sector can be considered to be a complex system. Complex systems are characterized by non-linear dynamic relations and feedback loops. This constitutes a reason why the behavior of the systems is not easily predictable. As a result, the decisions that regulate complex sectors might fail or have unexpected side effects [8].

In order to answer the sub questions and ultimately the research question a simulated model is created. The model is a method that is used for the exploration of complex systems when experiments are costly in resources, technically or physically impossible and have many variables that cannot be controlled. In the case of the energy sector, an experiment is not feasible and decisions on the definitive actions should be made.

3.1 Data Collection and Analysis

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. Then, investigating the reason why a parameter can cause specific changes in the behavior of the system is feasible. During the processes of creating the model and conducting sensitivity analysis, real life data will be used. In this way the validity of the data produced by the model can be checked.

During the validation process, simulations of the model run. These simulations produce data which will be analyzed as part of this thesis. The analysis will focus on the identification of patterns and rates within the data. Mainly, growth and saturation rates of different points of the system are going to be examined.

Most, if not all, of the data used for validation of the model is already collected by the dutch Central Bureau for Statistics (CBS)[3]. 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. In the appendix figures are attached that present the CBS datasets and provide useful insight into the Dutch energy sector over time.

[3]CBS

3.2 Modelling and Simulation

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.

For the development of the model, specific modelling software is used. The visual models that are going to be created are made in the software package Vensim [4] which is specifically designed for conducting system dynamics analysis. During this process different energy sources are going to be depicted and analysed. Vensim also enables the user to do sensitivity analysis over a large number of variables under different assumptions.

The data used for the sensitivity analysis of the model will be analyzed using the Python programming language [5]. Although, the results of the simulation can be analyzed both in Vensim or Python, the choice of python is made for more intelligent analysis. The PySD [6] module in python is specifically designed to be used on models build with Vensim.

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.

3.3 Anticipated Results

This thesis will have different research outputs. The first is a causal loop diagram that depicts the relations between different components of the energy sector in the Netherlands. Based on the causal loop diagram a stock and flow diagram is going to be constructed. The model is going to simulate the behavior of the system to capture different dynamical patterns. Finally, the model is going to be calibrated in order to quantify the relationships among its elements and explore its projection into the future. The sensitivity analysis of the model will propose and evaluate different scenarios that outline the direction and speed of the energy transition. In this way, insight on the parameters that fulfil the requirements of the Paris Agreement will be provided.

3.4 Evaluation of the model

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.

[4]Vensim
[5]Python
[6]PySD

3.5 Limitations of modelling

Every model is a representation of the reality and inevitable leaves things out depending on its boundaries. Therefore, it is important to realize that the model has a validity domain and only represents part of the energy sector system. The system dynamics approach does not focus on prediction, but mainly on understanding the interactions among the system components that influence the behavior system over time. Consequently, the outputs of the model's simulation and calibration might not exactly match the available data from the original system. Hence the model might have limited accuracy.

4 RISK ASSESSMENT

The main risks for this research are concerned with:

Data Limitations Although CBS, which will be the main source of data that is going to be used, provides very granular data, it is not specifically gathered for the purpose of this specific research. Therefore, it is important that this data is critically analysed before it is used in the model.

It might be possible that in the data exploration, important information about some of the model variables is not available at the CBS. In this situation the alternative would be to use statistics provided by literature and other sources.

Complexity of the model It is possible that the proposed initial model, that is going to be created throughout this research, will have high complexity. This would make the process of the calibration more complex. This could be resolved by scaling down the scope and adjusting the simulation model.

5 PROJECT PLAN

The table 1 below presents an overview of the week-by-week planning of the thesis project. A deliverable is expected at the end of each period. The deadlines are set by the university. This plan is subject to change depending on the the constraints that might arise, when this project officially starts.

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Table 1: Thesis Project Time Plan

Time Period	Task
Preparation: 01/03 - 07/03	Gather the necessary resources (related work, data).
Preparation: 08/03 - 15/03	Explore, analyse the data available on CBS. Create causal loop diagram.
Preparation: 16/03 - 23/03	**Data collection and Preparation Deliverable.**
Preparation: 24/03 - 31/03	Develop stock and flow diagrams.
Week 01: 01/04 - 07/04	Finalization and calibration of the models.
Week 02: 08/04 - 15/04	**Methodology and Experimental Setup Deliverable.**
Week 03: 16/04 - 23/04	Comparison of available data to the models outputs.
Week 04: 24/04 - 01/05	Calibration and optimization of the models.
Week 05: 02/05 - 09/05	Sensitivity analysis on the models.
Week 06: 10/05 - 17/05	Sensitivity analysis on the models.
Week 07: 17/05 - 24/05	**Analysis and Results Deliverable.**
Week 08: 25/05 - 02/06	Simulate models and analyse results.
Week 09: 03/06 - 10/06	Finalize the results section of the report.
Week 10: 11/06 - 18/06	**Discussion and Conclusion Deliverable.**
Week 11: 19/06 - 26/06	Incorporate the feedback provided in the report.
Week 12: 27/06 - 30/06	Finalise the report, check grammar, proof-read. **Submit final report on the 30th of June**.

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APPENDIX

Figure 1 shows the supply, transformation and the consumption of energy in a balance sheet. The data are available from 1946.

Figure 2 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.

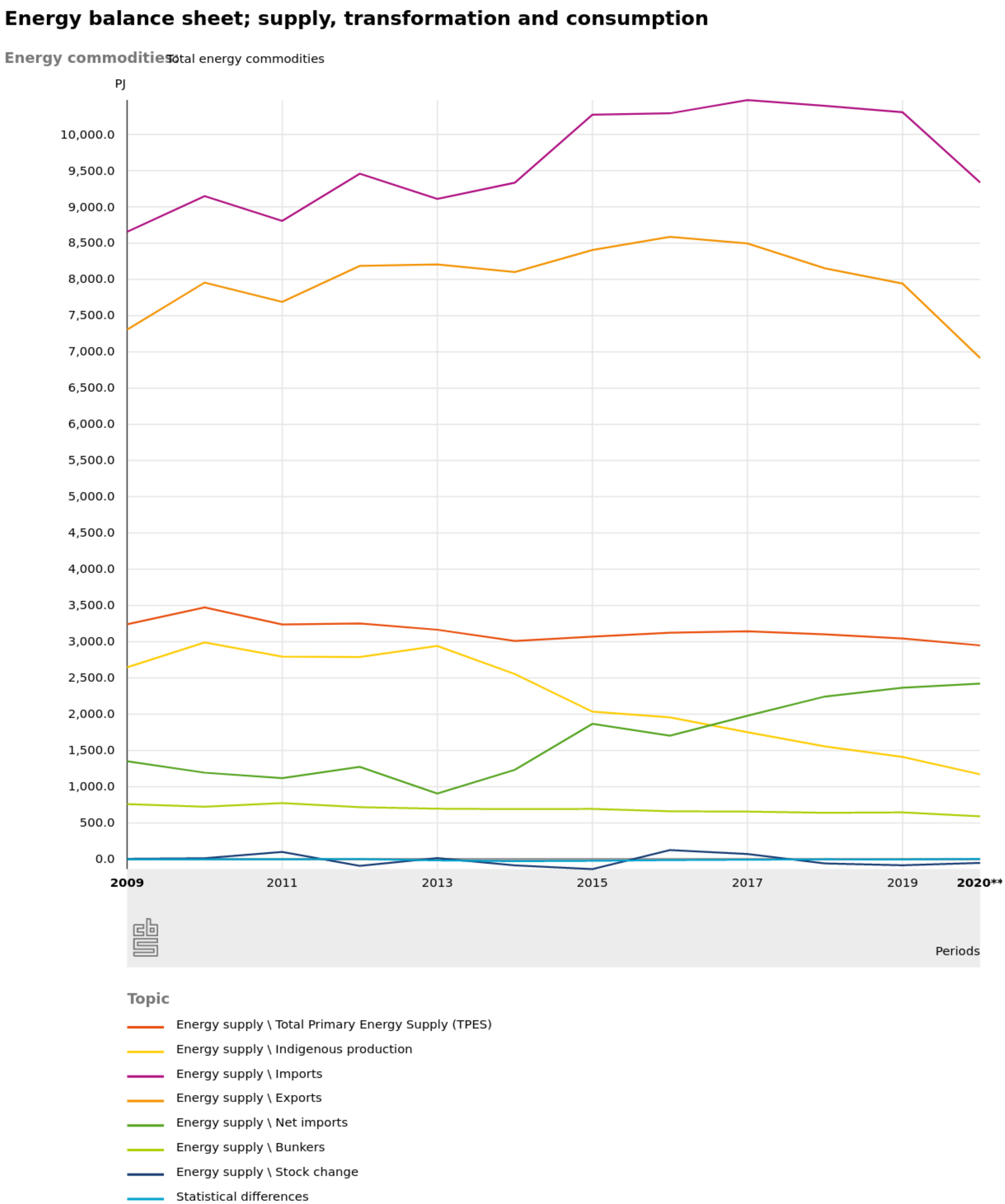

Figure 1: Energy balance sheet; supply, transformation and consumption

Renewable energy; consumption by energy source, technology and application

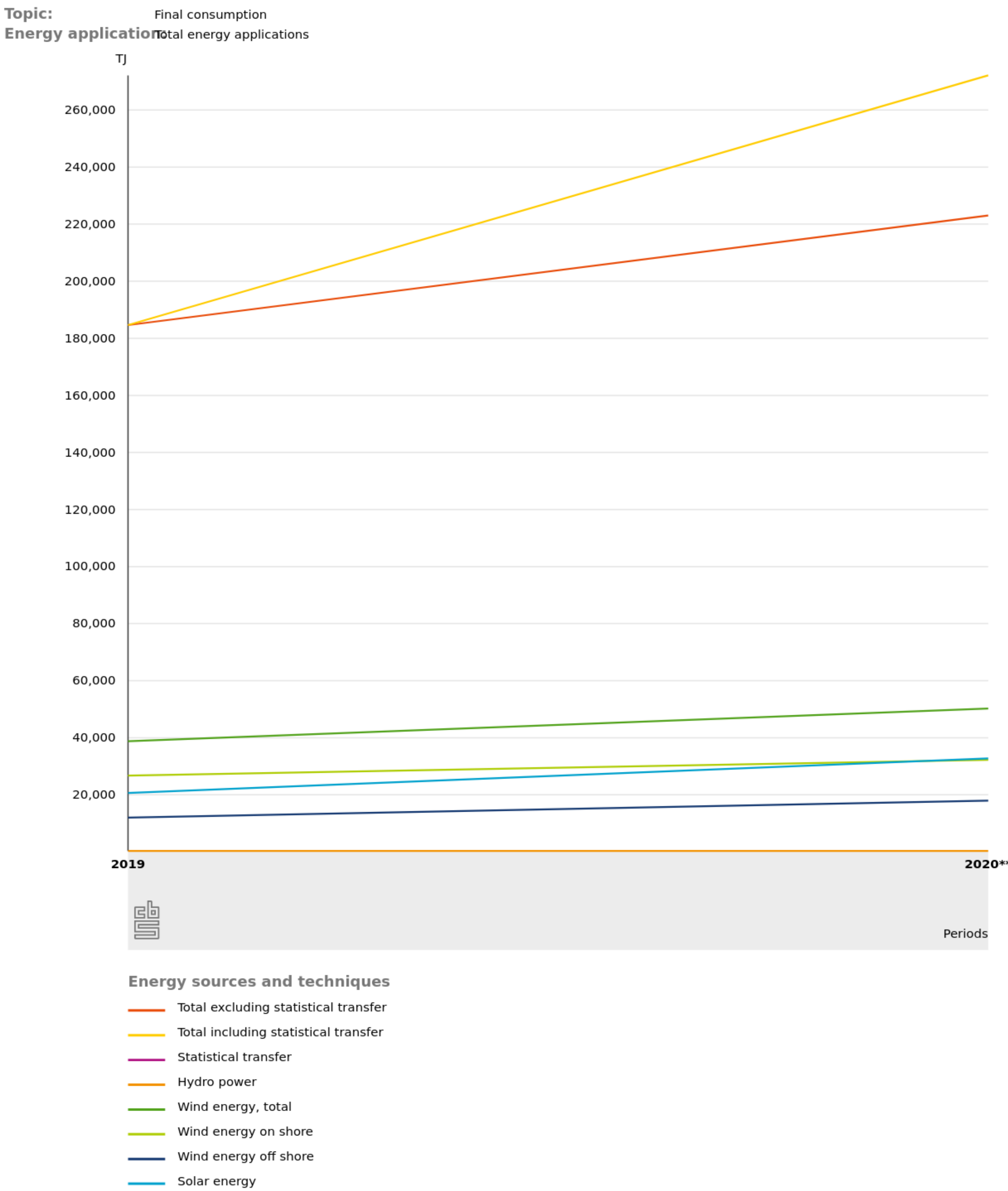

Figure 2: Renewable energy; consumption by energy source, technology and application