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Mines Douai

Work placement – Assistant engineer

AGH University of Science and Technology - Faculty of Energy and Fuel

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Location: Cracovia, Poland

Modeling of development of Polish energy system
Transport sector

May 2012 – August 2012

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Acknowledgements

I would like to thank Mr Artur Wyrwa to accept me in his team and to accompany me during the whole internship, Marcin Pluta for his precious help, and Januscz Zyśk and Kamila Drebszok for their sympathy and their help.

I am also grateful to Morgane Thomas for her advices.

A special thank to all the persons I met here, who made me discover their culture and their country, and for their welcome.

Introduction

Growing world's population and economic development require an increasing demand for energy, and an increasing access to energy. The oil crisis of the 1970's ended the area of unlimited cheap energy, whereas urban populations demand high level of transportation of people and goods, and building and operating the urban infrastructure, or industrial and commercial facilities, all require energy.

Moreover, the consequences on environment and public health of energy consumption placed more emphasis on the choices in energy sector for countries, which will ensure economic, social and environmental issues.

The research team of the Faculty of Energy and Fuel of AGH University of Science and Technology is currently providing scenarios for the next decades on Polish energy sector. To achieve this, it is necessary to model the Polish energy system.

In this context, Dr. inz. Artur Wyrwa accepted me as an intern from May 2012 to August 2012 and my mission was to create a model of the Polish energy system concerning the transport sector.

Abstract

The research team of the faculty of Energy and Fuels in AGH University provides analysis and scenarios about the Polish energy sector. This is a way to have the trend of the economic and ecologic impact of the evolution of the energy sector in the following years.

This report is concerning the internship I have made from the 14th of May 2012 to the 14th of August 2012 as part of the work described in the previous paragraph. The task was centered on the transport sector and its modeling in the global Polish energy system, with TIMES model generator. The model takes into account economic, environmental and technical parameters.

First, the work environment is described in order to understand the context of the mission. Then, the results and the methods to achieve it are presented, to finish with the personal impressions let by this internship and experience.

KEY WORDS

- Energy modeling
- Greenhouse gas emissions
- Transport sector
- Energy Systems
- Integrated Ressource Planning
- Fuels

Mission and targets

Model the Polish energy system

The research team of the Faculty of Energy and Fuels is actually taking part in a project, which aim is to model the **Polish energy system**. Whereas the residential and power sectors had already been modeled, the **modeling of transport sector**, in terms of energy systems, constituted my mission.

The transport sector

The transport sector is one of the main sectors of energy demand with residential, industrial and commercial sectors. Its characteristics are specific to each country.

TIMES model generator

To achieve this modeling, it was necessary to handle the TIMES model generator. TIMES has been developed by the Energy Technology System Analysis Program (ETSAP) of the International Energy Agency (IEA). It has been applied in many projects for analyzing energy systems.

Produce scenarios from now to 2030

In order to have some projections of the energetic situation in 2030. Even if the situation still remains uncertain in 2030, it helps to understand the consequences that might have some decisions, particularly European policies, on this sector.

I. Work environment

Poland

Figure 1: geographical location

Poland is a central European country which shares his frontiers with Germany, Czech republic, Slovakia, Ukraine, Belarus, Lithuania and Russia.

Figure 2: Poland map and neighbor countries

Energy sector

The major part of polish energy production comes from coal, since Poland owns large reserves, while oil is becoming more and more expansive and gas does not assure their energetic independence. Nevertheless, Poland is trying to diversify its energy mix. A nuclear program is planned and some researches are conducted on unconventional gas extraction: referring to studies, Poland has under his foots reserve for years of energetic independence, but ecological consequences remain uncertain. Renewable energies are also taking an increasing part in Polish energy mix.

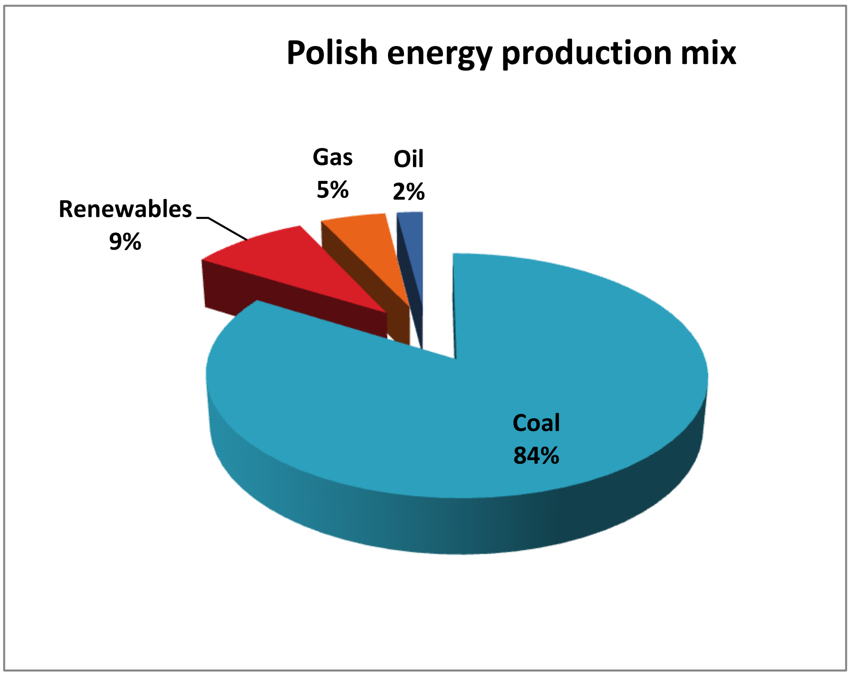


Figure 3 Fuel proportion for Polish power sector

Adaptation to European constraint

Poland took part in the European Union in 2004 and may expect to enter the euro zone in 2015, depending on the situation of current economic crisis. European member countries are encouraged to take measures in order to reduce their greenhouse gas emissions.

Transport sector

The transport sector accounts for nearly one-quarter of CO2 emissions in Europe and for one-quarter of final energy consumption in Poland.

AGH University

AGH University of Science and Technology consists of 15 faculties, educating more than 35,000 full time and extramural students as well as 550 doctoral students. As AGH University employs more than 2,000 research workers, the University has many links with industrial companies, both national and international.

Research team of the Faculty of Energy and Fuel

The faculty of energy and fuel is one of the youngest faculties of AGH University. It was created in 1991 in order to face the increasing demand of energy and fuels. At the beginning, the faculty focused on energochemical coal processing and development of sorbent technologies. From this time, the faculty extended its educational fields to new ones such as sustainable energy development or environment protection in chemical and power industry. The research team of the Faculty of energy and fuel is leading research on energy system in Europe.

Research team of the Faculty of Energy and Fuels

Artur Wyrwa, PhD and Assistant Professor at the Faculty of Energy and Fuels. His researches are mainly centered on modelling of development of energy systems and integrated ressource planning. The team is also composed by Marcin Pluta, Master of Science and Energy Specialist at the Faculty of Energy and Fuels, specialized on analysis of the development of Polish energy system, Januscz Zyśk, Master of Science and Energy Specialist at the Faculty of Energy and Fuels, focused on modeling of atmospheric dispersion of pollutants, and Kamila Drebszok, who works on the analysis of the impact of particle emissions on human health.

II. Work achievements

Context

The transport sector is strongly impacted by the technological evolutions and European policies, aiming to limit climate change and the impact on public health.

Climate change as a global challenge

Climate change is one of the most serious challenges in the 21st century. To avoid dangerous climate change, a variety of greenhouse gas (GHG) mitigation actions have increasingly been taken in all sectors of the global energy system.

Context in energy policy

The EU built a legal framework to reduce GHG emissions for the period after 2012, when the first commitment period of the Kyoto protocol ends.

The European Council supports an EU objective to reduce by 80-95% carbon emissions by 2050 compared to 1990 levels. The European parliament similarly endorsed the need to set a long-term reduction target of at least 80% of carbon emissions by 2050 for the EU and the other developed countries.

The Energy and Climate & Energy Package (CEP) was adopted by the European Council in 2009, including the goals of: a 20% reduction in greenhouse gas emissions compared to 1990, a 20% improvement in energy efficiency compared to forecasts for 2020, a 20% share for renewable energy in the total EU energy mix. Part of this 20% share is a **10% minimum target for renewable energy consumed in the transportation sector**. This goal is to be achieved by all EU Member States.

Under the Directive 2003/30/EC on the **promotion of the use of biofuels or other renewable fuels for transport**, EU established the goal of reaching a 5.75% share of renewable energy in the transport sector by 2010.

Under the Directive 2009/28/EC on the promotion of the use of energy from renewable sources this **share rises to a minimum 10% in every Member State in 2020**. Regarding the expand of biofuels use in the EU, the Directive aims to ensure the **use of sustainable biofuels** only, which generate a clear and net GHG saving without negative impact on biodiversity and land use. [1]

The evolution of transport sector

The **transport sector** is projected to account for **most of the growth in energy consumption**: people are travelling more, transportation of goods is increasing and automobiles are not improving efficiency as fast as desired. Transport accounts for around **one quarter of EU GHG emissions**, **32% of final energy consumption in Europe**, and is a key area for energy savings.

In addition, **EU transport depends on oil products for 96%** of its energy needs. This strong dependence is to be changed in the following years.

Motivation, objective and structure

In this context, the analysis conducted concerns the **Polish Energy system**, and centered on the transport sector, to better understand the **effects of these policies** on it, or to explore the different ways to **achieve the European targets**.

First will be presented the methodology to build the transport sector sub-model, then the different scenarios tested and the results of this analysis.

Modeling of energy system: the system analysis approach [2] [3]

The research team of the Faculty of Energy and Fuels is actually taking part in a project, which aim is to **model the Polish energy system**. Whereas the residential and power sectors had already been modeled, the **modeling of transport sector** constituted my mission.

Approaching **energy as a system** instead of a set of elements gives the advantage of identifying the most important substitution options that are linked to the system as a whole and cannot be understood looking at a single technology or commodity or sector.

System analysis applies systems principles to aid decision-makers in problems of **identifying**, **quantifying**, and **controlling a system**. While taking into account multiple objectives, constraints, resources, it aims to specify possible course of action, together with their risks, costs and benefits.

Identification of the area of study

1. Scope of the analysis

The specific objective of this study is to provide a model for the **transport sector of Poland**, and to analyze the effect of the **European policies on biofuels** on transport sector. This will also enable to have a framework for a **transport sub-model** which can be later integrated to a model covering all sub sectors.

To achieve this, it was necessary to master the **TIMES software** which will be presented in more details in another section.

2. Boundaries

The transport sector is studied only on the **geographical area of Poland**. The vehicles traffic will consequently be studied only on national territory and will not include exchanges and trade between Poland and other countries.

The sector transport modeled focuses on **end-use devices** and their parameters, considering that **energy services** are directly delivered by end-use devices, without considering useful energy. Conversion from final energy to energy services is defined by the **efficiency** and one **conversion factor** specific to each end-use device. **Final energy consumed** by these end-use devices is **considered as imports**, which will enable to integrate later this sub-model in the global Polish energy system.

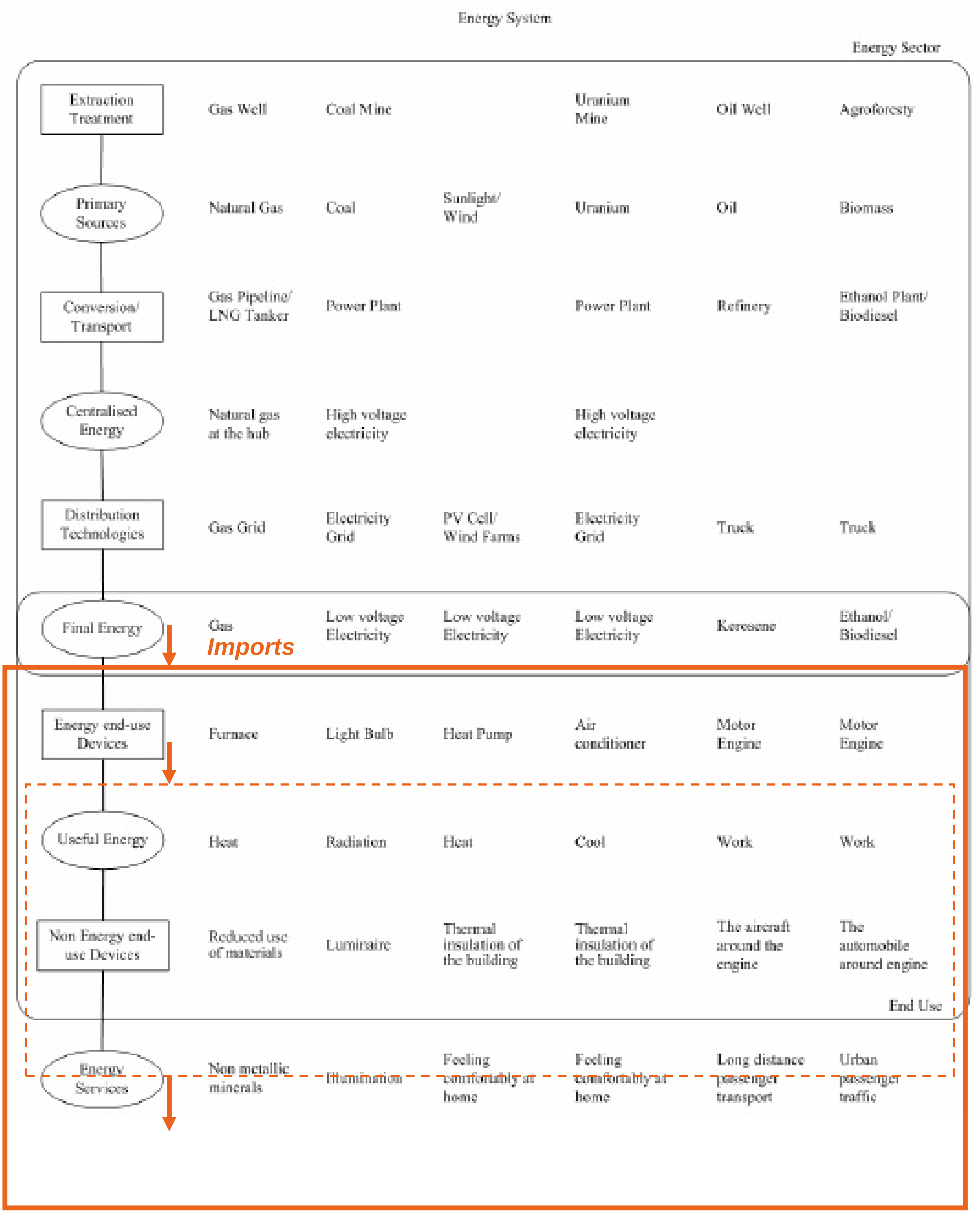


Figure 4 : Boundaries of the model in the global energy system

3. Time frames

The model focus on the evolution of transport sector on medium term: **from 2008 (called the base-year) to 2030**. As the production of electricity and heat, or gas supply and traffic is not detailed, the intra-annual variations are not modeled. The **time-slice** levels will always be "**ANNUAL**". Understanding possible future developments implies studying past behavior and reconstructing the present layout in an appropriate level of detail.

4. Components

There are two main components in the system: **commodities and technologies**.

Commodities represent all energy goods that flow in the system. This spans from primary sources such as coal or crude oil to final energy vectors, such as gasoline, heat or electricity. All this goods are normally **measured in energy units**. The category extends to include all **energy services** that the consumer needs, such as mobility, which is measured in Passenger*kilometer or Ton*kilometer for transport sector. This category also encompasses air emissions, or wastes to be disposed.

Technologies, called **processes** in TIMES software are the second essential element of the system. Energy supply processes include power plants and refineries, and transmission/distribution infrastructures. Are also included all devices that use the energy supplied by energy plants and infrastructures, here vehicles. In general, an analysis includes all identifiable stages that transfer energy from outside into the system and, inside the system from one energy good/service to another. In this category it is not easy to determine the level of detail that balance s the need to represent the actual nature of the system and that to keep the representation of the system a manageable size. Usually, hundreds of power plants are squeezed into a few dozens of classes, millions of refrigerators into few types, etc.

5. Connections: the Reference Energy System (RES)

The components, commodities and technologies, are then represented as a **Reference Energy System (RES)**, a network representation of all of the technical activities required to supply various forms of energy to **satisfy end-use activities**. Analytical formulations are described to examine all operations involving specific fuels including their extraction, refinement, conversion, transport, distribution, and utilization. Each of these activities is represented by a box (process) in the network for which **efficiency**, **environmental impact**, and **cost coefficients** may be specified. The processes are connected by links which represent the commodity. The network is quantified for a given year by the level of the energy demands, the energy flows through the supply activities (all associated technologies in a chain) that are required to serve those demands. The RES begins from the existing capacity in place, calibrated for the **base-year commodity flows**.

In addition, the RES contains technologies that, are known (or speculated) but not yet available on the market, or due to too high costs or lack of reliability are not competitive today, but may be commercial in the future. The Reference Energy System thus is a schema used to **represent the full structure of the energy system** being studied, at an appropriate level of detail.

Quantification

Once the system and its main components are identified, the estimate and **quantification step** can start. Depending on the **availability of statistical and technical information**, the identification of the system can be revised. On top of the usual difficulty of gleaning base information in sectors that sometimes protect their data for competition problems, the analytical problem here is to constitute a consistent framework. This often shows that not all data sources are reliable and additional assumptions/corrections are necessary.

1. Flows of energy commodities

The **energy flows** are described in EUROSTAT statistical database. It contains the **energy consumption for the base-year** and thereby holds the basic structure of the model. Sometimes, expert judgments assumptions are needed to **disaggregate the fuel consumption** down to **sub-sector** and **end-use levels**. Consumption of final energy by end-use has to match with the stock of devices, their power and their duration of use. If the stock is known with sufficient details, correlations and simple calibration procedure in spreadsheet

Once the splits are assigned, the commodity flows are quantified further to the level of useful energy, taking into account the **efficiencies of end use devices**, which thereby determines the implied stock in place, and thereby the resulting energy service demands. Analysts need a lot of patience in order to complete the partial quantification made available by energy statistical offices and ready it for the model. A lot of calibrations were needed for the transport model.

To make assumptions, sources on past evolution of the Polish transport sector were very useful. Most of data come from EUROSTAT statistics database. The next graph shows that cars are taking an increasing place in modal split of passenger transport, whereas demand for trains and buses tend to stabilize.

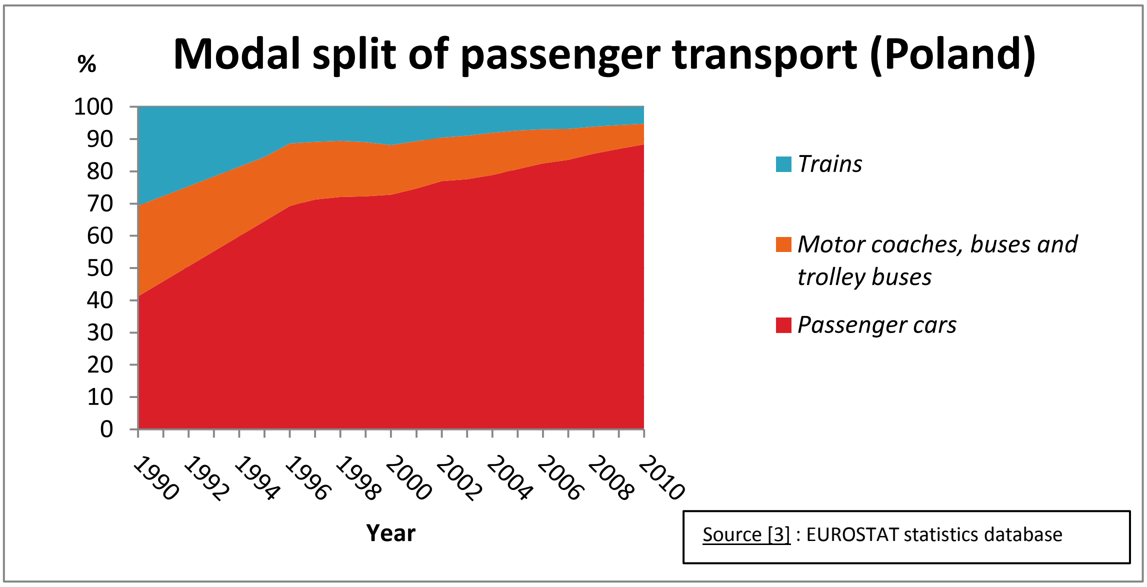


Figure 5 : Modal split of passenger transport

2. Energy technologies and end-use devices

Machines and devices are the most visible and durable part of an energy system. Thousands of them extract, transform, and distribute energy goods. For the analyses, **devices and processes similar by type or function** are usually grouped in clusters. These clusters are commonly addressed as “energy technologies”.

The transport sector

The transport sector is one of the main sectors of energy demand with residential, industrial and commercial sectors.

Specific tools and units that are required to work on transport sector and are used to model this sector:

- Vehicle movement, or traffic flow, is measured in vehicle-kilometer or Million vehicle-kilometer (VKm or MVKm**).** The distance to be considered is the distance actually run. Similarly, train movement is measures in train-kilometer.

- Transport demand has different units for goods transportation and passenger transportation. Goods transportation demand is usually quantified in Ton-kilometer or Million ton-kilometer (TKm or MTKm), and passenger transport in Passenger-kilometer or Million passenger-kilometer (PKm or MPKm).

Vehicle consumption or efficiency, especially for road vehicle, is often given in liters per 100km. To convert it in the unit of efficiency in energy system, conversion factors and vehicle movement detailed for each vehicle type is needed.

Use of the TIMES model generator

TIMES is a model generator which finds the optimal solution that maximizes the net total surplus in order to satisfy the energy services, by simultaneously making decisions on equipment investment and operation, primary energy supply and energy commodities trade.

It works with VEDA and GAMS, as presented in the next figure:

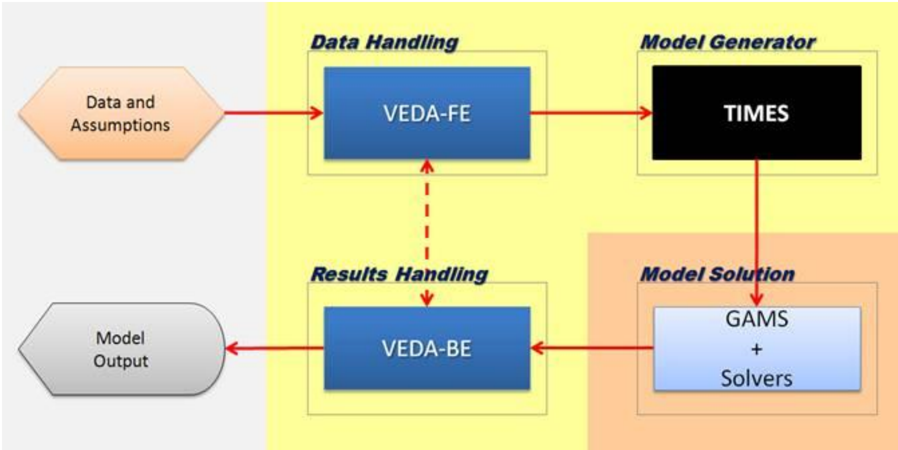


Figure 6 : Overview of the VEDA system for TIMES modeling (KanORS website)

The beginning of the internship period was dedicated to learn how the TIMES model generator was working and to understand it by building a small model in GAMS.

Scenarios

In the **Reference Scenario**, there are no constraints on the use of biofuels in transport sector. Therefore, **high biofuel prices** imply a strongly decreased consumption of biofuel in transport sector. This situation does not reflect the reality according to European policies and the real use of biofuels in transport sector in the past years that reflect an increasing of biodiesel for example. Two scenarios were tested concerning the influence of biofuels on Polish transport sector, putting a minimum use of biofuel in transport sector.

2010 biofuel consumption level

First scenario assumes that the future biofuel consumption is equal to the biofuel consumption in year 2010 until 2030.

High biofuel scenario

In second scenario, an increase of 2% per year in biofuel consumption is taken as hypothesis.

Results

The scenarios tested permitted to understand

Primary energy consumption

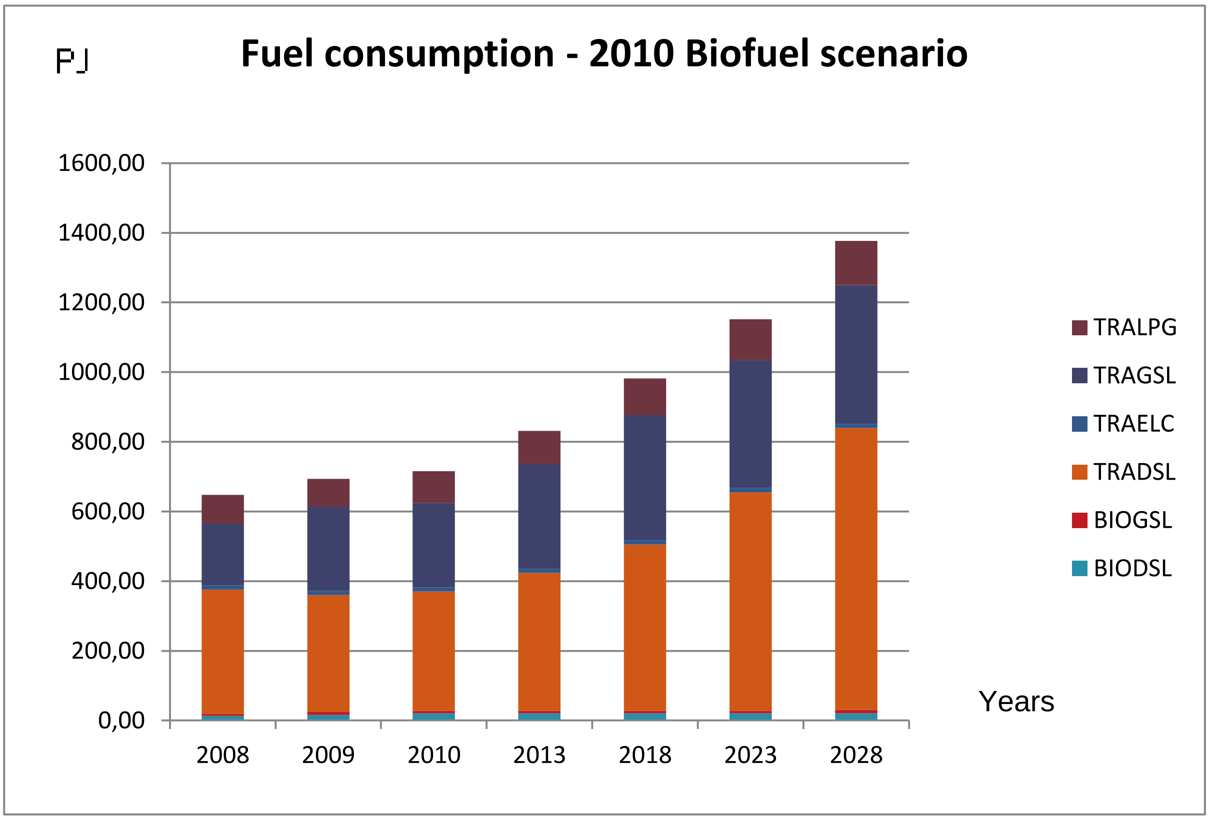
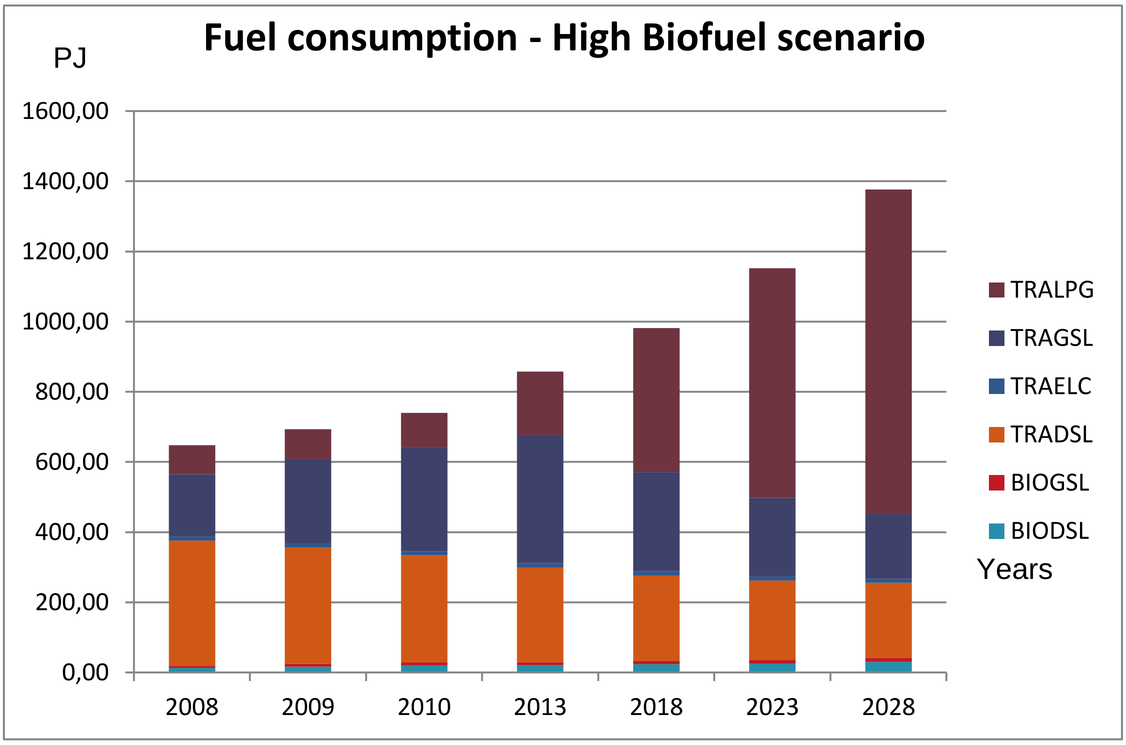


Figure 7 : Fuel consumption for first and second scenario



Fuel consumption is rising since transport demand is also rising. However the share of fuels changes depending on the constraints on the model and the assumptions made.

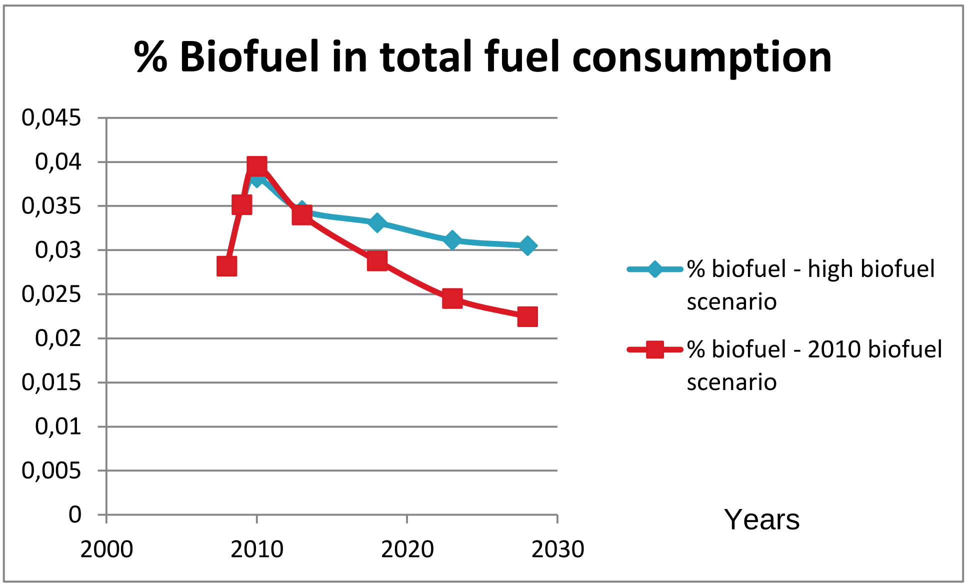


Figure 8 : Biofuel share in fuel consumption of transport

Even with a rise of 2% of biofuel consumption each year, the percentage of biofuel in total fuel consumption in transport sector is decreasing from 2010 and is far lower than the 10% which need to be reached for 2020, with the assumptions made.

Greenhouse gas emissions

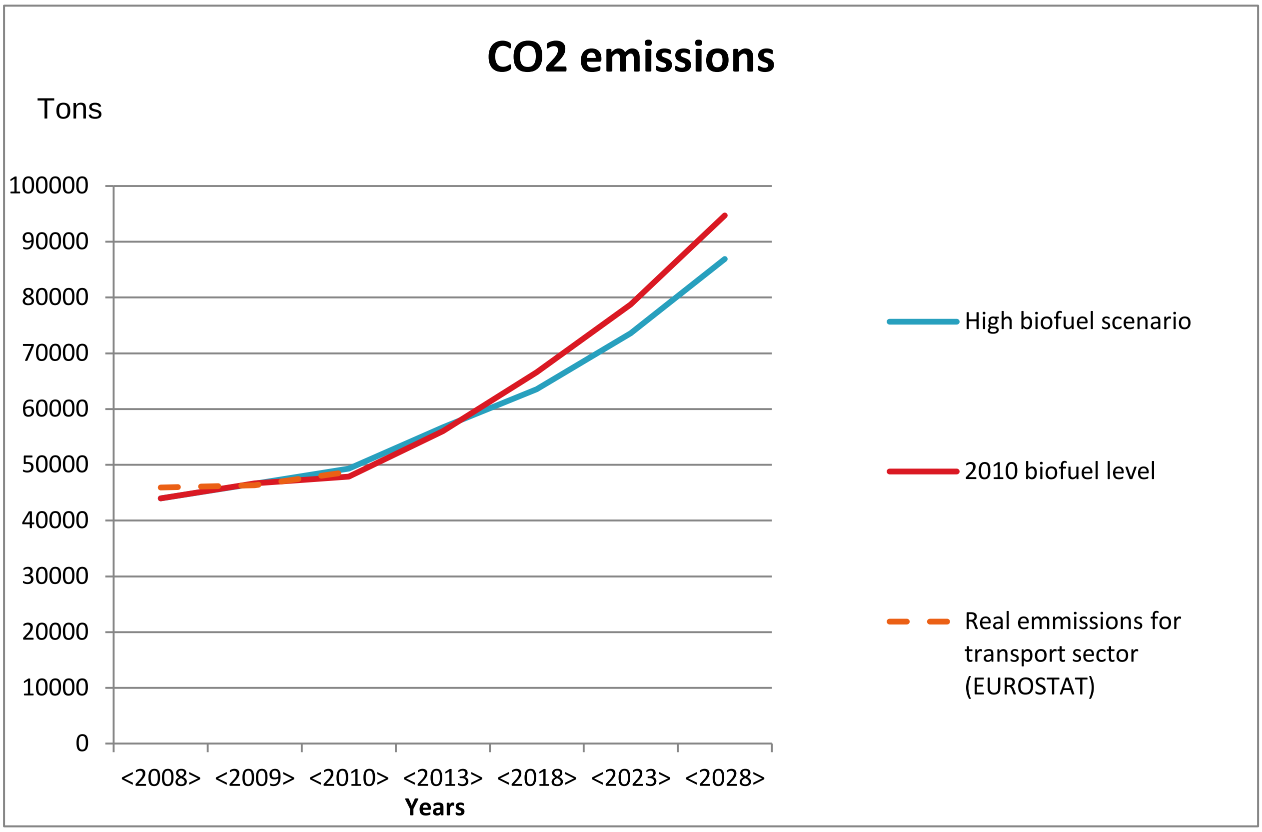


Figure 9 : CO2 emissions in different scenarios

CO2 emissions are rising, but the high biofuel scenario does not cut CO2 emissions as much as necessary.

Therefore, the assumption of a 2% increase in biofuel consumption is really not sufficient to meet the European targets for each member state.

Discussion and future of the model

This model is an abstract representation and we should keep in mind that the scenarios developed do not represent real forecasts. However, this enables to measure the tendency of the evolution of transport sector regarding the effects of technological advances and new policies.

The assumptions made in scenario for biofuels seem to prove that a 2% increase is not enough to reach European targets. However, some assumptions may be abusive in the model developed. The increase of the demand for road freight transport and cars passenger transport may be too high, and other scenarios need to be tested.

Other renewable sources for transport need to be added: the model does not take into account electric cars for example. EUROSTAT statistics do not indicate any use of electric cars (hybrid, full electric or other types) before year 2011, and statistics after this period are not available.

Some technical assumptions can also be updated like efficiencies which were taken from a former model.

Demand can be run with drivers like GDP or population instead of being specified for each period.

However, the structure of the model was built and runs well in TIMES model generator. This will be useful to rebuild a more developed model and to integrate it in the global Polish energy system. A document describing the structure of the model in detail, all the parameters and specific tools for the transport sector was left to the research office.

III. Personal impressions

This internship was a source of education in various domains.

Technical knowledge

To achieve the mission, it was necessary to apply some knowledge, especially on energy systems, methods of optimization to make decisions, and bases on current energy policies.

Developing a whole model for transport sector was very interesting, and made me become familiar with energy systems, modeling, and scenario building. I also learnt a lot about transport sector and its evolution.

Working on energetic issues in a country with a very different energetic context than in France made me discover a real different energy management than in France.

Human knowledge

My entire work was realized in English, and made me progress in this language.

This experience allow me to discover Poland and Cracovia, which is an exceptional city, which remain the former Polish capital, and the main cultural, historical, city in Poland. Living in Poland with people from a different culture during three month enabled to enhance my adaptation and communication capacities. It also confirmed my abilities to work in a team environment.

Professional project

The researcher profession has the advantage to make work on subjects in depth, and to work on projects that had never been conducted before. However, I would prefer to work in project engineering.

Conclusion

This placement as an assistant researcher, from the 14th May 2012 to the 14th August 2012, made me discover energy system modeling, specific tools to achieve it and scenario building. The model built for transport sector will be more developed in the future, and integrated to the global Polish energy system built by the research team.

It was a real opportunity to discover Poland, its cultural specificities and history, and to live a great experience in a foreign country.

This formation will be very useful for my future since I am making my specialty in the domain I want to work: Energy Engineering.

References

[1] http://ec.europa.eu (European commission website)

[2] *Getting started with TIMES-VEDA*, Maurizio Gargiulo, May 2009

[3] *Tools and methods for Integrated Resource Planning,* Joel N. Swisher, Gilberto de Martino Jannuzzi, Robert Y. Redlinger, November 1997

[3] http://epp.eurostat.ec.europa.eu (EUROSTAT)

[4] *Documentation for the TIMES model*, ESTAP, 2005

[5] The PRIMES Energy System Model Reference manual, European Commission Joule-III Programme

Appendix A – TIMES Veda Fe specific parameters

TIMES Veda FE initials	Name	Unit	Meaning for transport sector
AF	Availability Factor	Km	Maximum annual kilometers covered by a vehicle
Stock	Stock	Years	Number of vehicles of this type registered (thousand units)
Life	Life	Years	Life time of a vehicle (years)
FIXOM	Fixed Operating and Maintenance costs	€/year	Costs per year
VAROM	Variable Operating and Maintenance costs	MVKm	Costs per activity unit
EFF	Efficiency	MVKm/PJ	Vehicle efficiency
CEFF	Efficiency	MVKm/PJ	Vehicle efficiency depending on different commodities input or output of the process
ACTFLO~(Commodity name)	Conversion factor from activity unit to flow unit	Passenger or Ton per vehicle	Average amount of passengers or tons per vehicle
Demand	Demand	MPKm or MTKm	Demand for passengers or goods transport
Cap2Act	Capacity to activity factor	Thousands units	Conversion factor from capacity (thousand units) to activity unit (MVKm)
SHARE~OUT	Ratio of output commodity for one activity unit	-	Output commodity share for one vehicle.
SHARE~IN	Ratio of input commodity for one activity unit	-	Fuel share for one vehicle type

Appendix B – TIMES Veda BE specific parameters

TIMES Veda BE initials	Name	Unit	
VAR_Fin	Commodity input	PJ	Amount of fuel input to reach the constraints
VAR_Fout	Commodity output	MPKm or MTKm	Amount of commodity output of the process
VAR_Act	Activity of the process	MVKm	Vehicle movement
Var_Cap	Capacity of the process	Thousand units	Stock of vehicles

Appendix C – Assumptions and sources

ASSUMPTIONS AND SOURCES for TRANSPORT8 folder, stats sheet

Base-year data	Source	Additional assumption	Formulas for ajustment	Remarks
Final fuel consumption for road and rail	EUROSTAT	-		
Road passenger demand	EUROSTAT	Demand for Motorcycles from EU PAN model		
Road traffic	EUROSTAT	-		
Road freight demand	EUROSTAT	-		
Stock of road vehicles	EUROSTAT	-		
Car efficiency	PRIMES model 1995 and EU PAN model [5]	Different efficiencies for car long distance travel and car short distance travel		Need to be updated with more recent data
All road vehicles efficiencies (Liter/100Km)	PRIMES model 1995 and EU PAN model			Need to be updated with more recent data
All road vehicles efficiencies (MVKm/PJ)			= (Vehicle movement (MVKm) * Conversion factor (Lt/PJ)) / Vehicle consumption (Lt/100Km) *100/10^6	
Share of long and short distance travel for road vehicels	EU PAN Model	Share for long distance car travel is 20% minimum and 80% maximum		
Conversion factor ACTFLO (Passenger or Ton per vehicle)			= Vehicle movement (MVKm) / Demand (MPKm or MTKm)	
All FIXOM, VAROM and FCOST	EU PAN Model			
Rail demand (MPKM or MTKm)	EUROSTAT	-		
Rail traffic	EUROSTAT			

Tractive vehicle number for train	EUROSTAT	Split by passenger trains and goods trains (EU PAN model)	Tractive vehicle number for one end-use service = Total number of tractive vehicle for one vehicle type * ratio of vehicle movement	
Tractive vehicle movement	EUROSTAT	Split by passenger trains and goods trains (EU PAN model)	Tractive vehicle movement for one end-use service = Total tractive vehicle for one vehicle type * ratio of vehicle movement	
Train load = Conversion factor ACTFLO (Passenger or Ton per train)		Calculation from EU PAN model	= Demand (MPKm or MTKm) / Vehicle movement	
Tractive vehicle per train		Calculation from EU PAN model	= Tractive vehicle movement for one type and category / Train movement for one type and category	
Stock of trains		Calculation from EU PAN model	= Number of tractive vehicles / Tractive vehicle per train	
Train kilometer per train (Availability factor)		Calculation from EU PAN model	= Train movement / stock of trains	