Lock-in effects integrated into an energy system model:

how learning curves affect the amount of bio fuel used in the automotive transport sector of Germany.

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ABSTRACT

Developments in generating and storing energy are plentiful. Besides that, climate changes attract attention to the emission of CO_2 equivalents in the energy sector. A big contributor to the emission of CO_2 is the automotive transport sector. Usage of bio fuels can cause a reduction. However, their costs are too high for the consumer to be interested into buying them and the already present infrastructure of the fossil fuels makes investments flow towards fossil fuels instead of bio fuels. Fortunately, because the production of bio fuels is relatively new, a lot is learned which makes the costs drop. In this report it is researched how fast learning has to take place in Germany in order to make consumer choose one of the bio fuels ethanol, FAME, syndiesel or DME instead of the fossil fuels gasoline and diesel, i.e. in order to make lock-in of bio fuels occur.

For this the Balmorel energy system model, written in the GAMS language, is adapted. It incorporates the feedstock, production, import, distribution, refueling stations and usage of automotive fuels, calculating what capacity is needed when a fuel is used and more importantly how much this will cost, since this will determine which fuel is used.

The research concludes that lock-in in Germany of the bio fuel syndiesel occurs for a learning curve coefficient between -0.35 and -1.0. For the bio fuels ethanol, FAME and DME no amount of fuel is used, let alone that lock-in would occur.

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INTRODUCTION

We are at the dawn of an energy revolution. All around the world ways to generate and store energy are being developed and improved. For the generation of energy one could think of conventional resources as oil, gas and coal, and of alternative resources as nuclear energy, wind and the usage of land. This also involves the automotive transport sector. Ways to store energy in fuels range from conventional forms as gasoline and diesel to alternatives as ethanol and hydrogen. These developments in the area of energy can bring change to society as we know it today. Firstly, if the efficiency of fuels keeps on increasing we will need less of them and have money left for other things. Secondly, if alternative energy resources will be used, they can be generated everywhere, thus reducing the independence of countries on the import of oil and such. Finally, if we use less and cleaner fuels there will be a decrease in the rise of the amount of CO_2 equivalents emitted.

According to (UNEP and UNFCCC, 2002), average global temperature has risen by 0.6℃ in the twentieth century. Knowledge of this increase, a symptom of the greenhouse effect, caused members of the United Nations to sign the Kyoto protocol to slow down further increase. The greenhouse effect is caused by the release of gases, known among other names as CO_2 equivalents, when energy is produced. The transport sector requires a lot of energy. This means a lot of CO_2eq are emitted in this sector, making CO_2eq emission as well as energy in the transport sector a very interesting topic for study.

A first step in the study of this field was to describe the current status. In the report from the (European Energy Agency, 2000) data were made available that described the emission of CO_2eq by the automotive transport sector.

Next, projections into the future were made. Due to the inherent insecurity of the future this is rather complicated. In the (Balmorel) program flows of heat and electricity in the Baltic Sea area were simulated and their relation to CO_2eq emission measured. The report by the (Univ. of Athens, 2004) made for the European Commission constructed a number of very different scenarios for the future and calculated their impact on CO_2eq emission. These scenarios addressed oil and gas energy import prices, rate of growth for the Gross Domestic Product in the EU, rate of penetration concerning energy efficiency, the acceptance or phase-out of nuclear energy and finally promotion of railways. A final and important scenario concerned the rate of penetration of bio fuels.

Currently, bio fuels are locked out of the automotive fuel market and fossil fuels locked in. Lock-in means that a technology has become entrenched in the technological system (Cowan, 1996). Due to investments made in the past locked-in technologies are more economical in the present than other technologies.

Firstly of course, it was important to know what the benefits towards reduction of CO_2eq emission through the use of bio fuels in the transport sector could be. To this end, (EUCAR, CONCAWE and JRC, 2004) conducted a study in which Well-To-Wheel CO_2eq emission for different fossil and bio fuels were compared.

A great influence on the rate of penetration of bio fuels are their economies, i.e. costs per energy unit. In this field (Hamelinck, 2004) made a study to ascertain the viability of bio fuels now and in the future, and under which circumstances.

One part of economies is production costs. During production a lot of small and large decisions are made. Because similar decisions appear repeatedly, every decision is a bit better than the previous one; this is called learning (Albers et al., 1980). This learning causes improvements in time and efficiency for the production of a unit. Improvements in time and efficiency result in decrease of production costs. The mathematical representation of this phenomenon is called a learning curve.

This research deals with a specific part of all the options mentioned above; it tries to answer the following question.

For what rate of learning concerning the production of the bio fuels, ethanol, FAME, syndiesel and DME, does lock-in of these bio fuels occur in Germany, while minimalising overall costs and integrated into an energy system model?

Learning curves can be expressed in various ways. In this research the expression used by (Albers et al., 1980) and (Lowenthal, 1987) was chosen.

$$C(K_{cum}) = C_0 \cdot (K_{cum})^{LCC}$$

where

- C_0 is the cost per unit at the initial time t_0.
- K_{cum} is the cumulative capacity, i.e. all capacity in MW installed from time t_0
  $K_{cum} = \int_{t_0}^{t} K(t')\ dt'$
- $C(K_{cum})$ is the cost per unit when a cumulative revenue of K_{cum} has been made
- LCC, the Learning Curve Coefficient specifies the rate of learning ($-1 \leq LCC \leq 0$)

Cumulative capacity is taken as an indicator for the number of repetitions because it describes the amount of energy produced per time unit. The closer the LCC is to -1, the smaller the factor $(K_{cum})^{LCC}$ is and the more rapidly $C(K_{cum})$ decreases.

This report is structured as follows. Firstly, the research question is introduced. Secondly, used terminology is presented. Thirdly, the structure of the model is explained. Fourthly, the sources for used input data are treated. These last two chapters can be skipped without losing the main focus. Fifthly, how output data was analysed is described. Sixthly, output data is displayed. Seventhly, these are discussed. Eighthly, the report is concluded. Ninthly, the product and the process are evaluated. Finally, used literature and the appendices are displayed.

RESEARCH QUESTION

This research tried to find an answer to the following question:

For what rate of learning concerning the production of the bio fuels, ethanol, FAME, syndiesel and DME, does lock-in of these bio fuels occur in Germany, while minimalising overall costs and integrated into an energy system model?

The following conceptual model is devised on which the sub questions are based:

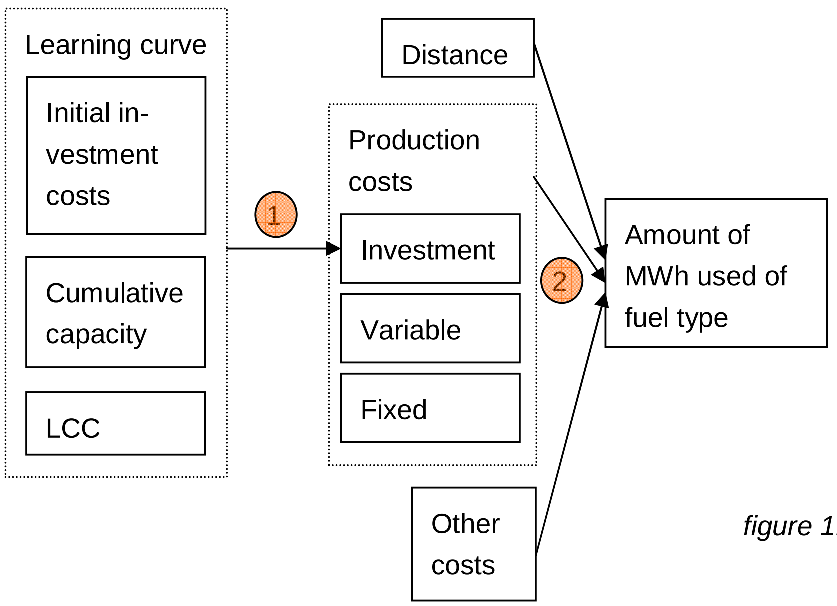

figure 1.1: Conceptual model
H.B.Meerwaldt, 2005

Sub questions

1. What are the investment costs for the production of bio fuels at every time step given the initial investment costs, the cumulative capacity and the LCC?

   In this research the investment costs decrease through learning using the following representation of a learning curve: $C(K_{cum}) = C_0 \cdot K_{cum}^{LCC}$ (Lowenthal, 1987). Where C_0 are the initial investment costs, K_{cum} is the cumulative capacity i.e. the sum of all capacity in MW installed until now, LCC is the Learning Curve Coefficient (-1 < LCC < 0) and $C(K_{cum})$ are the investment costs when a cumulative capacity of K_{cum} has been installed. The investment costs decrease more rapidly when the LCC is closer to -1. Another way of looking at the LCC is through $C(2 \cdot K_{cum}) = 2^{LCC} C(K_{cum})$. This means that when the cumulative capacity increases by a factor 2, the investment costs for production increase by a factor 2^{LCC} (but remember -1 < LCC < 0).

2. What amount of a fuel in MWh is used given the distance driven, the production costs and the other costs for that fuel?

   What fuel type a person chooses to use is influenced by a lot of factors. Factors include fuel cost, vehicle cost, distance driven, age, gender, income and employment (Rouwendal and de Vries, 1998). To keep the complexity this research already has to a minimum, only the influence of distance driven and costs determining fuel and vehicle cost, which are built up out of production and other costs, will be reviewed. The distance driven and the fuel cost influence the decision by determining the variable costs a person has for driving. The vehicle cost influences the decision by determining the fixed and variable costs a person has for driving.

Terminology

Gasoline and **diesel** are fossil fuels, i.e. they are derived from crude oil. Gasoline requires more preparation than diesel. Both consist of long strings of carbon with hydrogen. (C_xH_y)

Ethanol is that alcohol which can be found in beverages. It can be made from sugary, starchy and cellulosic plants. Then it is a bio fuel and is called bio ethanol and bio alcohol. It can also be made from fossil fuels.
(CH_3-CH_2-OH)

FAME or Fatty Acid Methyl Ester has properties equal to diesel. It is made out of oil or fat. Other names are biodiesel, RME when made from rapeseed and SME when made from soybean. FAME is a bio fuel. (C_xH_y)

Syndiesel has properties equal to diesel and is made synthetically, i.e. not derived from crude oil. It is a bio fuel and also called Fischer-Tropsch or FT diesel when made from this process. GTL (Gas-To-Liquids) and BTL (Biomass-To-Liquids) are FT processes. (C_xH_y)

DME or Di-Methyl-Ether is to diesel what LPG is to gasoline. It is a gas at room temperature but can be made liquid through small pressure. DME is a bio fuel. (CH_3-O-CH_3)

Emission of **CO_2eq** means the total emission of the gases CO_2, CH_4, N_2O, HFCs (HydroFluoroCarbons), PFCs (PerFluoroCarbons) and SF_6 that add to the green house effect. The emission of a single gas is multiplied with its GWP (Global Warming Potential) and is then comparable to CO_2.

Lock-in of a technology means the technology is entrenched in a technological system in such an amount making it uneconomical to change to another technology.

RESEARCH DESIGN

In this research the automotive fuel market was simulated using a computer model. This model was written in the (GAMS) programming language using the structure from (Balmorel). This model describes electricity and heat flows in the Baltic Sea area. The demand, being the total number of kilometres driven in Germany, is specified. The model has to meet the demand with a supply of fuels. The fuels are the fossil fuels gasoline and diesel, and the bio fuels ethanol, FAME, syndiesel and DME. The model simulates the entire process of supply, i.e. from feedstock and production or import through distribution and refuelling stations, and finally to usage. Like in reality the model chooses the cheapest option which normally would result in bio fuels not being chosen. For this reason, constraints based on policy from the European Union are added to the model.

A GAMS model

Firstly, I will discuss a typical (GAMS) model. A (GAMS) model always has the following structure:

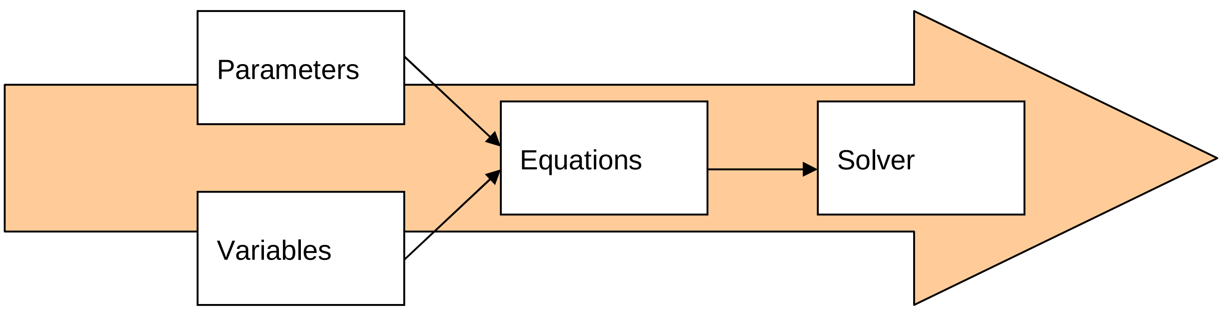

figure 2.1: Structure of GAMS model
H.B.Meerwaldt, 2005

Equations consisting of parameters and variables are solved by a solver.

Parameters are fixed data entered into the program by the user. Parameters exist in three forms. Firstly, sets are nothing more than lists with elements. They do not have a value. For example:

SET COUNTRIES /GERMANY, NETHERLANDS/
SET DATASET /AREA, INHABITANTS/

Secondly tables are functions of sets; they assign values to one or more sets. For example:

```
TABLE DATA(COUNTRIES, DATASET)
                 AREA     INHABITANTS
GERMANY          value    value
NETHERLANDS      value    value
```

Thirdly scalars are single values not depending on sets. For example:

```
SCALAR MAXINHABITANTS /value/
```

Variables are not entered by the user but calculated by the program, i.e. the program assigns a value to them. They can (but don't have to) depend on sets. For example:

```
VARIABLE IMMIGRANTS(COUNTRIES)
VARIABLE TOTIMMIGRANTS
```

Equations tell the program what values should be assigned to the variables. For example:

```
EQUATION1 ..
TOTIMMIGRANTS =E= SUM(COUNTRIES, IMMIGRANTS(COUNTRIES) )

EQUATION2 ..
MAXINHABITANTS =G= SUM(COUNTRIES, DATA(COUNTRIES, 'INHABITANTS') +
IMMIGRANTS(COUNTRIES) )
```

Equation one describes that the total number of immigrants equals the sum of the number of immigrants of all countries individually. Equation two says that the number of inhabitants and immigrants in all countries shouldn't exceed the maximum number of inhabitants.

The **solver** solves the equations. One variable must be selected to be optimalised, i.e. for this variable the solver will find its largest or smallest value that is allowed by the equations. The equations act as constraints. Also a method of solving should be selected, in this case linear programming. For example:

```
SOLVE EQUATIONS USING LP MAXIMIZING TOTIMMIGRANTS
```

Model description

Now, the model used in this research is discussed. It had the following parameters, variables and equations.

Parameters

The path a fuel goes through is pictured in the model as showed in this diagram. For every phase except feedstock and import a set of specific technologies is chosen for the model.

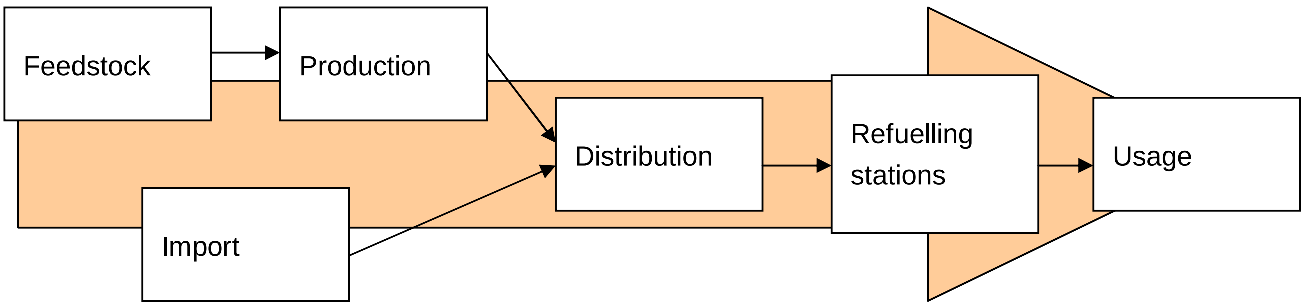

figure 2.2: Structure of the fuel path
H.B.Meerwaldt, 2005

<u>Feedstock</u>

No fuel used for cars is found in nature. Instead, a feedstock found in nature is converted into a fuel. Especially for bio fuels usually more than one kind of feedstock is suitable to produce a fuel out of. In this research the following kinds of feedstock were selected. In this research all feedstock is assumed to be imported.

Table 2.1: Fuels and its feedstocks

Fuel	Feedstock
Gasoline	Crude Oil
Diesel	Crude Oil
Ethanol	Wheat
	Sugar Beet
FAME	Rapeseed
Syndiesel	Wood Waste
DME	Wood Waste

<u>Production</u>

All fuels are produced in Germany. The fuels gasoline and diesel are produced by a refinery out of crude oil. These processes were viewed with this amount of detail:

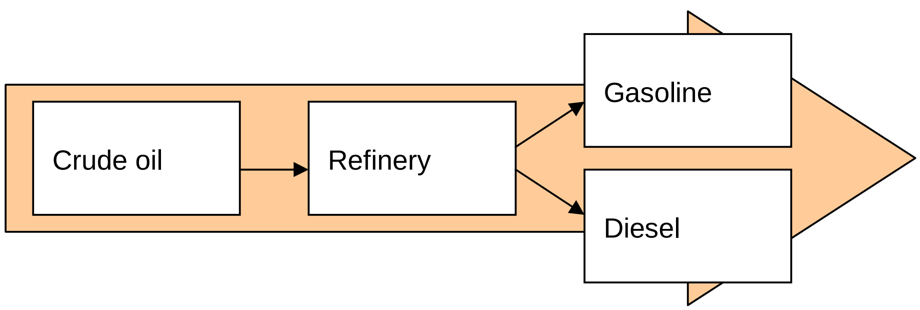

figure 2.3:
Structure of production of gasoline and diesel
H.B.Meerwaldt, 2005

In this research the following methods for producing ethanol out of wheat and sugar beet are pictured. The structural integrity of wheat is destroyed through the process of milling. Using hydrolysis the starch inside the wheat is converted into sugar. Sugar beet needs milling to be converted into sugar. Next, the sugar is fermented into ethanol with the use of yeast.

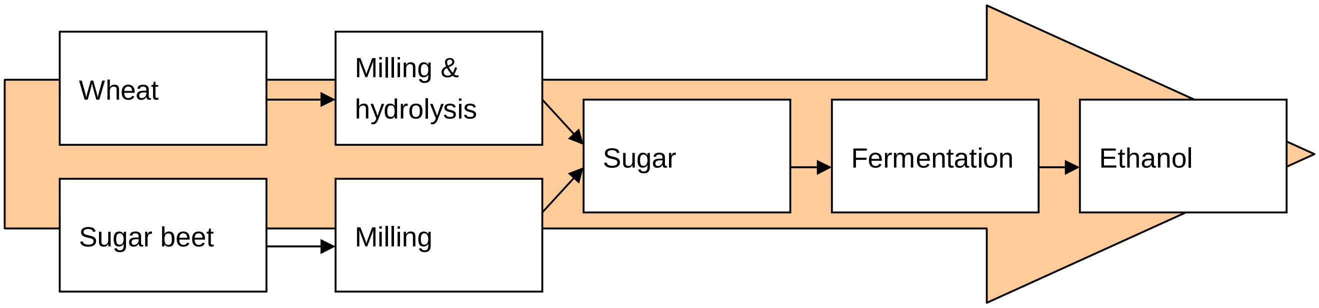

figure 2.4:
Structure of production of ethanol
H.B.Meerwaldt, 2005

FAME is produced out of rapeseed, this is an oil seed. Firstly, the oil is pressed out of the seed. Finally this vegetable oil is transformed into FAME through the use of esterification; to the triglycerides in the oil methanol is added to form glycerol and esters which are extracted.

triglyceride + methanol → glycerol + esters

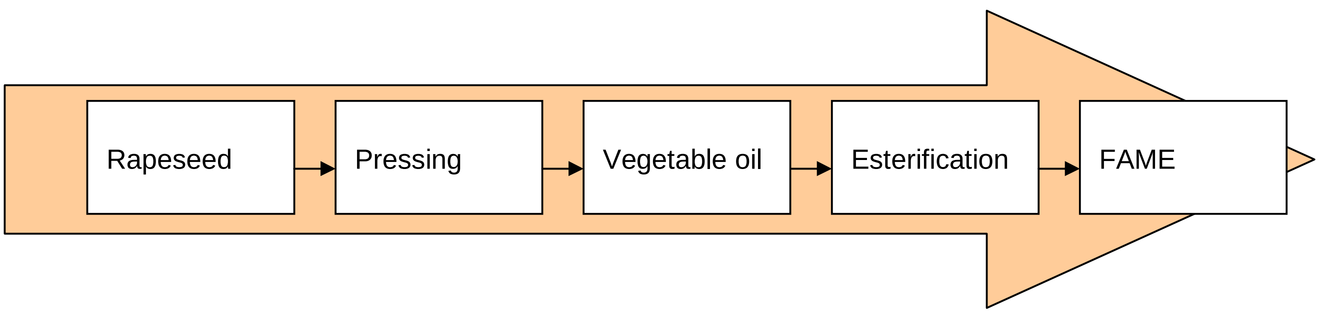

figure 2.5:
Structure of production of FAME
H.B.Meerwaldt, 2005

Syndiesel and DME are produced out of wood waste. Firstly the wood waste is gasified into syngas. This is a mixture of CO and H_2. Finally through catalysed synthesis the syngas is turned into syndiesel or DME.

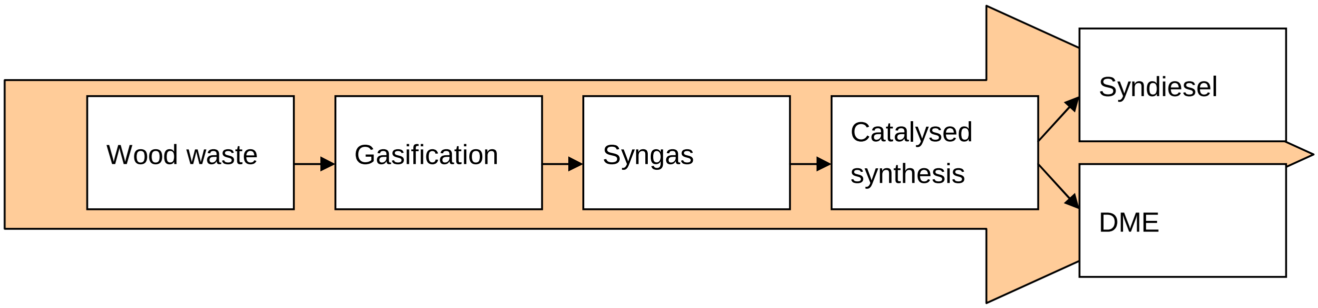

figure 2.6:
Structure of production of syndiesel and DME
H.B.Meerwaldt, 2005

Import

Instead of producing the fuel, for gasoline and diesel, the model also has the opportunity to import them. The ratio between production and import is kept fixed using historical values. This aspect is not investigated and therefore the model should be constrained to be as realistic as possible.

Distribution

When the fuel reaches Germany after being produced or imported, it has to be distributed throughout the country. In this model trailers are used for that. The average distance is chosen to be 700 km. They are assumed to be able to make one loaded trip to and one empty trip from the destination per day.

Refuelling stations

Next, the fuels are distributed to the refuelling stations.

<u>Usage</u>

Finally, the fuels are used, i.e. people drive cars using the fuels. Only passenger cars are taken into account. In the model 18 different vehicles are available; for every fuel there are three classes of cars, determined by the cylinder capacity of the engine (in litres). This division is clarified by the next table.

Table 2.2: Fuels and cylinder capacity classes for vehicles

C.C. / fuel	0 – 1.4 l	1.4 – 2.0 l	2.0 l +
gasoline			
diesel			
ethanol			
FAME			
syndiesel			
DME			

For every phase in the path the technologies have values for different parameters. The next table shows which parameters are used in which phase.

Table 2.3: Parameters used for each phase

phase / parameter	Feed-stock	Production	Import	Distribution	Refuelling stations	Usage
Investment costs		x			x	x
Annuity		x			x	x
Fixed costs		x			x	
Variable costs	x	x	x	x		
Capacity		x		x	x	
Full load hours		x		x	x	
Feedstock input		x				
LCC		x				
LCC2		x				
Cluster		x				
Efficiency						x
Lifetime						x
CO_2eq emission		x		x	x	x

When a production site, a refuelling station or a vehicle, in short a unit, is needed, it has to be purchased first. The costs for this are the *investment costs.* Trailers, i.e. distribution units, are not purchased in this model but hired so they do not have investment costs.

The *annuity* is the percentage of the investment costs that has to be paid each year to cover interest and make an instalment.

The *fixed costs* have to be paid regardless of how much energy is handled at the unit. It is expressed as a percentage of the investment costs. Fixed costs for vehicles are not taken into account.

Finally *variable costs* have to be paid. These are the costs per MWh feedstock or fuel. For the phases feedstock and import this just means the price for buying for example a MWh of wood waste or a MWh of gasoline. For the phase production these costs are deduced from the amount of electricity required or produced. This means variable costs for production can be negative. For the phase distribution these are the costs to deliver one MWh of fuel from the production or import site to the refuelling station and return back to the site. Variable costs for vehicles are not taken into account due to insignificant differences between the fuels and are therefore irrelevant for the model.

Besides what has to be paid, also what is possible is important. The *capacity* tells how much MW (not MWh!) a unit is able to handle.

Going together with the capacity are the *full load hours*. This tells the model how many hours per year the technologies are capable of delivering fuel at the rate of MW specified by capacity. How many MWh a vehicle is able to use is not determined by capacity and full load hours, which are difficult to tell, but by demand of kilometres which will be described later on.

In order to determine how much feedstock has to be purchased, the model needs the *feedstock input*. This is the amount of MWh feedstock necessary to produce 1 MWh of fuel.

The learning curve was described earlier in this report. The parameters *LCC* and *LCC2* are the learning curve coefficients used in the model. Parameter LCC2 is determined as follows. The learning curve:

$$C(K_{cum}) = C_0 \cdot (K_{cum})^{LCC}$$

requires knowledge of the value for the initial investment costs C_0. Because these are not easy to be found, but current investment costs are, the initial investment costs can be described by the current investment costs and the cumulative capacity installed until current time.

$$C_{current} = C_0 \cdot (K_{cum\ until\ current})^{LCC} \Rightarrow C_0 = C_{current} \cdot (1 / K_{cum\ until\ current})^{LCC}$$

Which rewrites the learning curve to:

$$C(K_{cum\ from\ current}) = C_{current} \cdot (K_{cum\ from\ current} / K_{cum\ until\ current})^{LCC}$$

Furthermore, because learning also takes place outside Germany, the capacity has to be multiplied by a factor z, which changes the learning curve to:

$$C(K_{cum\ from\ current}) = C_{current} \cdot (K_{cum\ from\ current} / LCC2)^{LCC}$$

with: $LCC2 = z / K_{cum\ until\ current}$

Some production technologies involve the same processes and therefore learning in a process affects all production technologies using this process. For this reason every production technology is assigned to a *cluster*. Technologies in a cluster have the same LCC.

Finally an amount of energy in the form of fuel reaches the vehicle and can be used. Now it is important to know how many energy is needed to travel one kilometre. This is expressed in the *efficiency*.

Of course vehicles don't live forever. They deteriorate and finally break down. The model needs to know the *lifetime* of a vehicle. After the lifetime expires a new vehicle has to be purchased. Many vehicles are sold before their lifetime ends, but this means they are also bought. Change of ownership is irrelevant to the model.

Special interest in this project goes to the *CO2eq emission* by the automotive transport sector. CO2eq emission is expressed in g CO2eq / MWh fuel produced, distributed, refuelled or used.

Besides parameters concerning the various technologies, the model also needs other parameters.

- Firstly, the *demand* is required. This is specified as the total amount of kilometres that is driven in the whole of Germany in one year.

- Secondly, the demand is not uniform. The three vehicle classes do not comprise the same number of vehicles and therefore not the same amount of kilometres. Furthermore not every vehicle drives the same amount of kilometres in a year. The *demand distribution* tells what part of the amount of kilometres is driven by a certain vehicle class and a certain kilometre class. It adds up to 1 and is clarified by the next table.

Table 2.4: Kilometre and cylinder capacity classes for each vehicle

C.C. / km / year	0 – 1.4 l	1.4 – 2.0 l	2.0 l +
0 – 10000			
10000 – 20000			
20000 – 30000			
30000 +			

- Thirdly, the *historical number of vehicles* that were present in Germany in the period 1995-2005 is entered, leaving less room for deviation by the model.

- Fourthly, the *bioratio* sets for each year what part of all MWh energy used has to come from bio fuels. It is explained further in the sub chapter 'Approach'.

Finally, internal parameters are needed. They are either given in advance to determine what is simulated or calculated by the program.

- The period in *years* to be simulated
- The countries, regions and areas to be simulated. In this research Germany was chosen as the single country, region and area. With more areas transport between areas must be taken into account.
- Number of production sites, trailers, refuelling stations and vehicles present at the moment. This number is updated when new ones are built or, in the case of vehicles, reach the end of their lifetime.
- Learning curve factor. Using the learning curve coefficients this factor is used to determine which part of the investment costs remain.

Variables

After all the input data is entered into the program, it should be told what the output should be. For every technology the following two variables are calculated:

- Number of new units purchased this year.
- Amount of energy (MWh) produced, imported, distributed, refuelled and used this year. The amount of feedstock needed is calculated out of the amount of energy produced and is not a variable.

Finally the variable that will be optimalised is needed. In this model total costs are minimalised. All variables are positive and continuous. Although of course there is no such thing as half a car, using continuous variables severely reduces calculation time compared to discrete variables.

Equations

The point where it all boils down to are the equations. The equations can be divided into two categories:

- Objective function
- Constraints

The following equations are simplified for displaying purposes. The variables are underlined. The objective function says the total costs must equal the sum of all three types of costs of all technologies:

TOTAL COSTS =E= SUM(TECHNOLOGIES, (INVESTMENT COSTS + FIXED COSTS + VARIABLE COSTS))

where for every technology goes:

INVESTMENT COSTS =E= ANNUITY * LEARNING CURVE FACTOR * INV. COST PER UNIT * # OF NEW UNITS

FIXED COSTS =E= FIXED COST PERCENTAGE * LEARNING CURVE FACTOR * INV. COST PER UNIT * # OF NEW UNITS

VARIABLE COSTS =E= VARIABLE COST PER MWh * MWh

For feedstock:

VARIABLE COSTS =E= VARIABLE COST PER MWh * FEEDSTOCK INPUT * MWh PRODUCTION

Here immediately two questions arise:

- When a new unit is installed due to the annuity only a part of the investment costs are paid, but the next year, the unit isn't new anymore and nothing is paid. Shouldn't this part of the investment be paid until all of the investment costs are accounted for?
- When a new unit is installed fixed costs are paid, but the next year, the unit isn't new anymore and nothing is paid. Shouldn't fixed costs be paid for all existing units?

The answers are no and no. Of course in real life you should pay all of the investment costs and the fixed costs although the unit is not new anymore. In the model these costs do not involve any of the variables and are therefore irrelevant.

The constraints can be divided into flow and limitation equations. The flow equations make sure that figure 2.2 is followed through correctly, e.g. it is not possible to use more energy than is distributed and the MWh used is specified by the exogenously given demand of kilometres.

MWh PRODUCTION + MWh IMPORT =E= MWh DISTRIBUTION

MWh DISTRIBUTION =E= MWh REFUELLING STATIONS

MWh REFUELLING STATIONS =E= MWh USAGE

MWh USAGE =E= DEMAND DISTRIBUTION * km DEMAND * EFFICIENCY

Some of the limitation equations make sure the amount of MWh handled doesn't exceed that allowed by the existing units, e.g. it is not possible to produce ethanol without an ethanol production site (=L= means "less than").

MWh =L= (# OF NEW UNITS + # OF EXISTING UNITS) * CAPACITY * FULL LOAD HOURS

For usage:

MWh =L= (# OF NEW UNITS + # OF EXISTING UNITS + HISTORICAL # OF UNITS) * EFFICIENCY * km PER UNIT

The ratio between production and import is set:

MWh PRODUCTION =E= RATIO * MWh IMPORT

The fossil fuel limitation equation specifies what part of total MWh used has to be by bio fuels. It is explained further in the sub chapter 'Approach'.

MWh BIO FUEL USED =G= BIORATIO * MWh USED

Summarised, energy by usage is forced by the equation with demand. Through the flow equations energy by refuelling stations, distribution, import and production is forced. Through the limitation equations the purchase of units is forced. The fossil fuel limit forces bio fuels to be used. Total costs depend on energy handled and number of new units. While complying with these equations the total costs are minimalised through the objective function.

Solver

The equations are solved for the first year, then all internal parameters are updated and the equations are solved for the next year. All equations are linear; therefore the linear solver CPlex is used.

```
LOOP(YEARS,
SOLVE EQUATIONS USING LP MINIMIZING TOTAL COSTS
# OF EXISTING UNITS THIS YEAR = # OF EXISTING UNITS LAST YEAR + # OF NEW UNITS
LEARNING CURVE FACTOR = (# OF EXISTING UNITS * CAPACITY / LEARNING CURVE COEFF 2) ^ LEARNING CURVE COEFF 1
)
```

Approach

In order to answer the research question the following approach to use the model was chosen. For the years 1995 to 2030 two scenarios concerning the bioratio were constructed. The first scenario has a constant bioratio of zero, i.e. it sets no constraints on how much bio fuel has to be used.

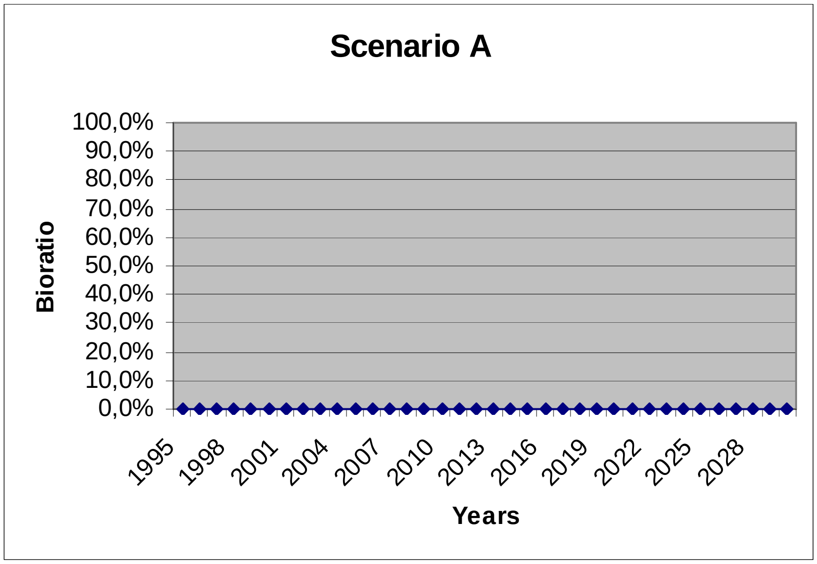

figure 2.7: Bioratios used in scenario A
H.B.Meerwaldt, 2005

Test runs however have shown that no bio fuel is used in this scenario. When no bio fuel is used, no learning can occur and the bio fuel never gets cheap enough to be used. For that reason bio fuels were chosen to be forced into the model using the bioratio. Values for the bioratio were chosen according to EU goals. These say that until 2010 5,75% of all fuel used for transport have to be bio fuels and until 2020 10%. In order not to shock the model by suddenly significantly having to change which fuels are used, these goals were spread over a couple of years. This means not in every year until 2010 5,75% is bio fuel, but the average is.

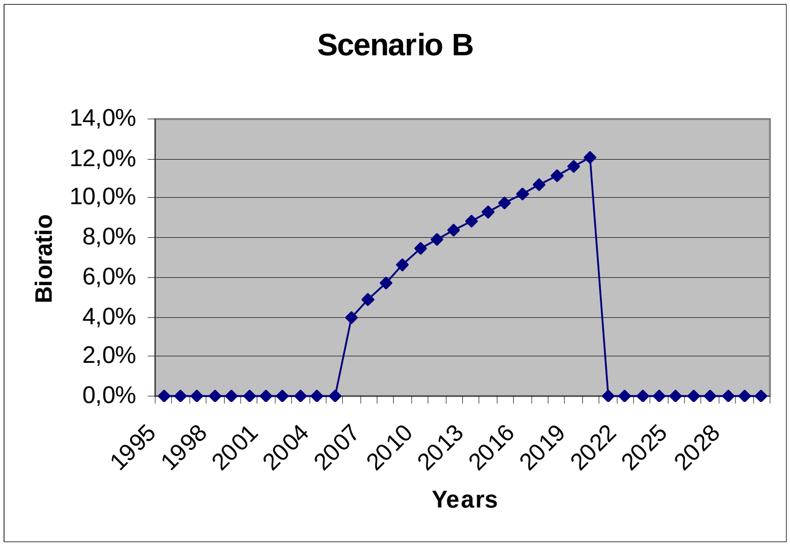

figure 2.8: Bioratios used in scenario B
H.B.Meerwaldt, 2005

From 2021 on the constraints were released. Now it is possible to see how much is learned by the bio fuels and in what amount they will be used when they are not forced.

For scenario B four different sub scenarios were built. They are determined by the LCC for the bio fuels. They were taken to be equal. This means the production of ethanol, FAME, syndiesel and DME improves with the same LCC. In all scenarios gasoline and diesel have an LCC of 0.

Table 2.5: LCCs for bio fuels in different scenarios

Scenario	LCC
B1	0
B2	-0.35
B3	-0.4
B4	-1.0

This means in scenario B1 learning proceeds slowest and in scenario B4 fastest.

These five scenarios were entered into the model as input values. They were not chosen randomly; runs were made with LCCs from -1 to 0 in intervals of 0.05. These values were chosen in this report to form the scenarios in order to portray certain types of output. Finally, the amount of MWh energy was reviewed for all fuels to find out if lock-in had occurred. This is discussed in the chapter 'Analysis'.

Type of research

This research can be categorised as being descriptive. Reasons for this are:

- For scenarios based on different LCCs and different fossil fuel limits, the amount of fuel used is calculated for every fuel. This means a property (i.e. amount) of a unit (i.e. a fuel) is described.
- If the production costs for a certain fuel decrease, this fuel is used more. This relation is inherent to the model and was not investigated in this research. This research described the energy situation for different scenarios and no relations were explored.
- Besides that no new relations were sought, no theory or hypothesis was tested.

ANALYSIS

Next, output from the model was reviewed. To be able to answer the research question the amount of bio fuels used after 2020 was analysed. Then five possibilities exist.

1. No bio fuel is used at all. This means although no investments into production, distribution, refuelling stations or vehicles for bio fuels have to be made, bio fuels are still too expensive.

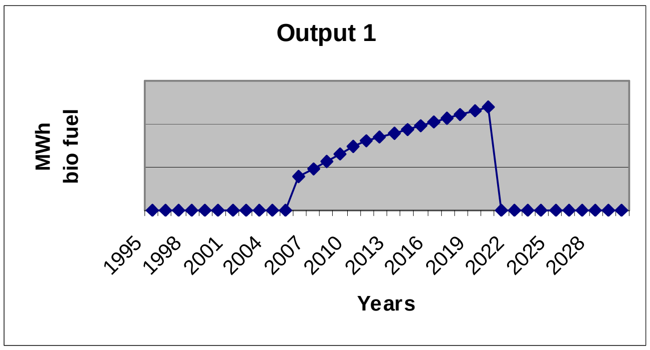

figure 3.1: Amount of bio fuel used in 'output 1'
H.B.Meerwaldt, 2005

2. The amount of bio fuel used drops gradually. This means the bio fuels are cheap enough to be bought, but only until a new vehicle has to be purchased, because the lifetime for the old one expired. Then the use of a fossil fuel is chosen.

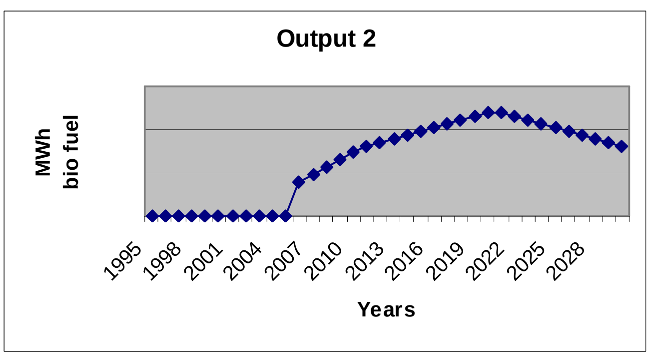

figure 3.2: Amount of bio fuel used in 'output 2'
H.B.Meerwaldt, 2005

3. The amount of bio fuel remains at the level of 2020. This means the bio fuels are cheap enough, even when a new vehicle has to be bought. However, investment costs for production are still too high to purchase new bio fuel production sites to meet the rising demand.

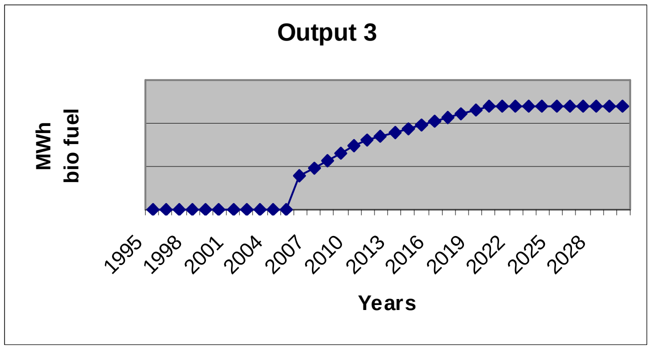

figure 3.3: Amount of bio fuel used in 'output 3'
H.B.Meerwaldt, 2005

4. The amount of bio fuels rises. This means the investment costs for bio fuels are low enough to have bio fuels being chosen, even when this means new production sites have to be built.

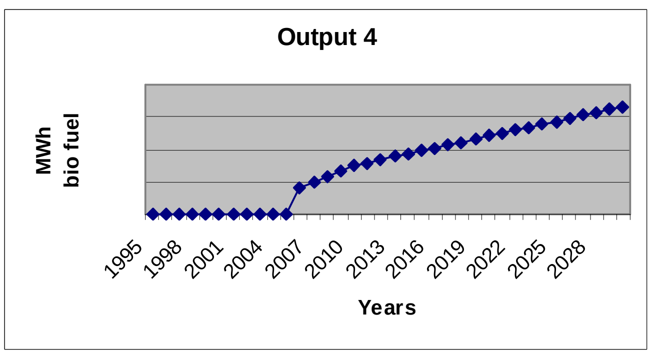

figure 3.4: Amount of bio fuel used in 'output 4'
H.B.Meerwaldt, 2005

5. Being a mixture of point 3 and 4; the amount of bio fuels remains at the level of 2020 but eventually starts to rise. The prices for gasoline and diesel rise gradually. This means the investment costs for bio fuels are only low enough after a certain level for gasoline and diesel prices is reached.

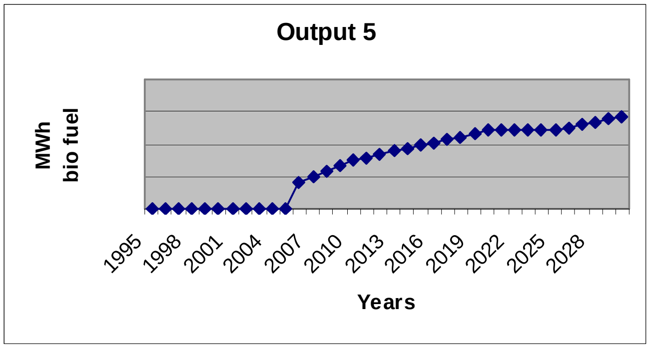

figure 3.5: Amount of bio fuel used in 'output 5'
H.B.Meerwaldt, 2005

In this research the learning curve factor is defined to have caused lock-in when 'output 4' or 'output 5' has been reached. With X being the MWh bio fuel, three conditions can be set:

1. For all years i after 2020: $X_i \geq X_{2020}$
2. For all years i after 2020: $X_{i+1} \geq X_i$
3. For at least one year i after 2020: $X_i > X_{2020}$

Output 3 was not chosen to represent lock-in because total MWh rises and therefore the percentage bio fuel usage drops; entrenched technologies are not assumed to lose share. Reasons for not assigning lock-in to output 1 and output 2 are clear.

According to the learning curve the investment costs decrease monotonically in relation to the LCC. This means when $LCC_A < LCC_B$, then for all years: inv. $costs_A <$ inv. $costs_B$. This means that when lock-in occurs for a certain LCC, lock-in will also occur for every LCC that is lower. If lock-in doesn't occur, it will not occur for any LCC that is higher.

PREPARATION OF INPUT DATA

In this chapter is shown what values are used for the parameters. Some of these values are taken directly out of literature; some are calculated out of literature values. For some parameters assumptions were made.

Investment costs

For production and vehicle investment cost values taken from (Hamelinck, 2001) in €$_{2003}$ were corrected using the Harmonised Consumer Price Index, 1.044, from (Eurostat, 2005) to €$_{2000}$. For the production of gasoline and diesel another approach was chosen. Instead of having the costs be determined by investment and fixed costs, which are difficult to tell due to the complexity of refineries and the interdependence between gasoline and diesel production, the market prices for gasoline and diesel were used. For refuelling stations an investment cost of € 300,000 was assumed.

Table 4.1: Investment costs for technologies

Fuel	Feedstock	Production Inv. costs €$_{2000}$	Ref. stations Inv. costs €$_{2000}$	Usage Inv. costs €$_{2000}$
Gasoline	Crude Oil	0	300,000	15,802
Diesel	Crude Oil	0	300,000	17,239
Ethanol	Wheat	268.2	300,000	16,856
	Sugar Beet	142.7		
FAME	Rapeseed	380.2	300,000	17,239
Syndiesel	Wood Waste	279.7	300,000	17,239
DME	Wood Waste	293.1	300,000	17,718

Annuity

The annuities for production, refuelling stations and vehicles are taken to be 0.1175, i.e. 11.75% of the investment has to be paid in a year.

Variable costs

The feedstock costs for the bio fuels are taken from (Hamelinck, 2004) and corrected into €$_{2000}$ using the HCPI, 1.044, from (Eurostat, 2005). The costs for crude oil are taken for each year from (M.W.V., 2003). For forecasts into the future annual prices changes of -3.27% for 2000-2010, 1.74% for 2010-2020 and 1.59% for 2020-2030 were taken from (Univ. of Athens, 2004). All feedstock is imported.

The variable costs for production of bio fuels are calculated from amount of electricity that has to be purchased/can be sold for each MWh of product at a price of € 0.03/kWh$_{elec}$, both from (Hamelinck, 2004). Variable costs for gasoline and diesel are calculated as being the difference between import gasoline and diesel prices on the one hand and crude oil prices on the other hand, averaged in the period 1997-2003.

Only the import of gasoline and diesel is allowed. These prices are taken from (M.W.V., 2003). For forecasts into the future, the variable production costs are added to the crude oil prices.

For the distribution a price of €$_{2003}$ 1.24 / km is taken from (Hamelinck, 2004) and converted into €$_{2000}$ using the HCPI, 1.044, from (Eurostat, 2004). Using the capacity which is displayed later on, a variable price in €$_{2000}$ / (km * MWh) is calculated.

Table 4.2: Variable costs for technologies

Fuel	Feedstock	Feedstock Var. costs €$_{2000}$ / MWh	Production Var. costs €$_{2000}$ / MWh	Import Var. costs €$_{2000}$ / MWh	Distribution Var. costs €$_{2000}$ / (km * MWh)
Gasoline	Crude Oil	see app. I	5.9	see app. I	0.00669527
Diesel	Crude Oil	see app. I	3.6	see app. I	0.00700633
Ethanol	Wheat	34.5	-22.7	n/a	0.01062706
	Sugar Beet	48.3	1.7		
FAME	Rapeseed	22.8	-11.1	n/a	0.00795694
Syndiesel	Wood Waste	10.3	2.2	n/a	0.00682514
DME	Wood Waste	10.3	1.8	n/a	0.01062706

Capacity

For the production of bio fuels the value of 400 MW feedstock (Hamelinck, 2004), corresponding to the before mentioned investment costs was recalculated to MW fuel with the use of the feedstock input, displayed later.

The capacity for distribution was calculated using the following simple formula.

CAPACITY(MW) ~ CAPACITY(tonne) * HIGHER HEATING VALUE(MWh/tonne) / FULL LOAD HOURS * # OF TRIPS PER DAY

Capacity in tonnes was taken from (Probas, 2005), corresponding to CO_2eq emission values mentioned later on, and has a value of 13.5 tonne. Higher heating values for each fuel were taken from (Hamelinck, 2004). Full load hours will be displayed later on. Number of (round) trips per day was chosen to be 1.

The capacity for refuelling stations was chosen to be 1 MW.

Table 4.3: Capacities for technologies

Fuel	Feedstock	Production Capacity MW	Distribution Capacity MW	Ref. stations Capacity MW
Gasoline	Crude Oil	n/a	3.70	1
Diesel	Crude Oil	n/a	3.53	1
Ethanol	Wheat	76	2.33	1
	Sugar Beet	148		
FAME	Rapeseed	124	3.11	1
Syndiesel	Wood Waste	168	3.63	1
DME	Wood Waste	232	2.33	1

Full load hours

The number of full load hours for production of bio fuels was taken from (Hamelinck, 2004). For refuelling stations, values were assumed. The values for production of fossil fuels and for refuelling stations were taken from (Probas, 2005).

Feedstock input

Values for feedstock input for production of bio fuels were calculated out of fuel efficiency values from (Hamelinck, 2004). For the fossil fuels values from (Probas, 2005) were used.

Table 4.4: Full load hours and feedstock input for technologies

Fuel	Feedstock	Production Full load hrs h/a	Production Feedstock input MWh feedstock / MWh fuel	Distribution Full load hrs h/a	Ref. stations Full load hrs h/a
Gasoline	Crude Oil	8000	1.01	8760	5000
Diesel	Crude Oil	8000	1.01	8760	5000
Ethanol	Wheat	8000	5.26	8760	5000
	Sugar Beet	8000	2.70		
FAME	Rapeseed	8000	3.23	8760	2000
Syndiesel	Wood Waste	8000	2.38	8760	5000
DME	Wood Waste	8000	1.72	8760	2000

LCC

The values for the LCCs are chosen as is discussed in the sub chapter 'Approach'.

LCC2

Values for the LCC2 for the bio fuels, expressing cumulative capacity until current time and relation to foreign learning, are assumed to be 100.

Clusters

The production technologies were divided into 4 clusters according to similarity in the production process. Every technology in a cluster has the same LCC.

Table 4.5: Clusters, LCCs and LCC2s for technologies

Fuel	Feedstock	Cluster	LCC	LCC2
Gasoline	Crude Oil	1	0	n/a
Diesel	Crude Oil	1	0	n/a
Ethanol	Wheat	2	see 'Approach'	100
	Sugar Beet	2	see 'Approach'	100
FAME	Rapeseed	3	see 'Approach'	100
Syndiesel	Wood Waste	4	see 'Approach'	100
DME	Wood Waste	4	see 'Approach'	100

Efficiency

Values for the efficiency for gasoline and diesel vehicles for the three cylinder capacity classes were calculated using formulas from (European Energy Agency, 2000), expressing g fuel/km as a function of velocity, integrated over a NEDC drive cycle from (EUCAR, CONCAWE and JRC, 2004). Values for the classes from ethanol were calculated using the proportion in efficiency to gasoline, taken from (EUCAR, CONCAWE and JRC, 2004). Values for the classes from FAME, syndiesel and DME were calculated using the proportion in efficiency to diesel, taken from (EUCAR, CONCAWE and JRC, 2004). Values for efficiency can be found in appendix II.

Lifetime

Lifetime for all vehicles and classes was 12 years, taken from (EUCAR, CONCAWE and JRC, 2004).

CO_2eq emission

Values for the emission of CO_2 equivalents for gasoline and diesel vehicles was calculated from g/km values taken from (EUCAR, CONCAWE and JRC, 2004) into g/MWh values using efficiency values as mentioned above. The emission from bio fuel vehicles was taken to be 0, because every gram of CO_2 equivalent that is emitted has been taken from the air in the past by the feedstock for the bio fuels; bio fuels are CO_2eq neutral.

Table 4.6: Lifetime and CO2eq emission for usage

Fuel	Usage Lifetime a	Usage CO_2eq emission g / MWh
Gasoline	12	2.42e5
Diesel	12	2.69e5
Ethanol	12	0
FAME	12	0
Syndiesel	12	0
DME	12	0

Values for the CO_2eq emission by production are taken from (EUCAR, CONCAWE and JRC, 2003). For CO_2eq emission by distribution and refuelling stations, values from (Probas, 2005) were used, depending on fuel used by trailer for distribution and electricity used at refuelling stations.

Table 4.7: CO2eq emission for technologies

Fuel	Feedstock	Production CO_2eq emission g / MWh	Distribution CO_2eq emission g / MWh	Ref. stations CO_2eq emission g / MWh
Gasoline	Crude Oil	2.15e5	7.6	64.1
Diesel	Crude Oil	2.91e5	8.0	64.1
Ethanol	Wheat	1.22e6	12.1	64.1
	Sugar Beet	6.58e5		
FAME	Rapeseed	2.55e5	9.0	64.1
Syndiesel	Wood Waste	0	7.8	64.1
DME	Wood Waste	0	12.1	64.1

Demand

The amount of kilometres demanded by German passenger cars was taken from (DIW Berlin, 2005). Projections into the future were made through extrapolation. They can be found in appendix III.

Demand distribution

Distribution of demand by kilometre class was calculated through the use of the stock of vehicles in Germany from (DIW Berlin, 2005). For calculating the distribution of demand by vehicle class the average (14381 km), the median (11497.5) and the standard deviation (9818.5) were taken from (IVT, 2004). Using the Weibull distribution values for the different classes could be constructed. The vehicle class and the kilometre class distributions were multiplied.

Table 4.8: Demand distribution after kilometre and cylinder capacity class

C.C. / km / year	0 – 1.4 l	1.4 – 2.0 l	2.0 l +
0 – 10000	0.059	0.110	0.031
10000 – 20000	0.107	0.199	0.055
20000 – 30000	0.068	0.127	0.035
30000 +	0.061	0.114	0.032

Historical number of vehicles

The values for the stock of vehicles onto 2003 were taken from (DIW Berlin, 2005). Values for the future decrease a part of one divided by the lifetime. They can be found in appendix IV.

RESULTS

In order to answer sub question 1:

What are the investment costs for the production of bio fuels at every time step given the initial investment costs, the cumulative capacity and the LCC?

for each scenario the production costs will be shown for every year. For the bio fuels this will mean the investment and fixed costs for the first year and the feedstock costs that are required per km driven with the bio fuel. For the fossil fuels this means variable costs and feedstock costs per km driven with the fossil fuel.

Answering sub question 2:

What amount of a fuel in MWh is used given the distance driven, the production costs and the other costs for that fuel?

requires a graph which displays amount of fuel in MWh for each fuel, for each kilometre and vehicle class and for each scenario, not forgetting other costs for all fuels. This graph is much too complicated to be shown. For this reason a computer model was used in the first place.

To answer the main research question:

For what rate of learning concerning the production of the bio fuels, ethanol, FAME, syndiesel and DME, does lock-in of these bio fuels occur in Germany, while minimalising overall costs and integrated into an energy system model?

graphs for different scenarios, meaning different rates of learning, are displayed which contain amount of fuel used for each year. Using these graphs, lock-in can be tested as described in the chapter 'Analysis'.

Scenario A

With no restrictions made to the amount of gasoline and diesel used, the production costs and the amount of fuels used looks as is shown in figure 5.1 and 5.2.

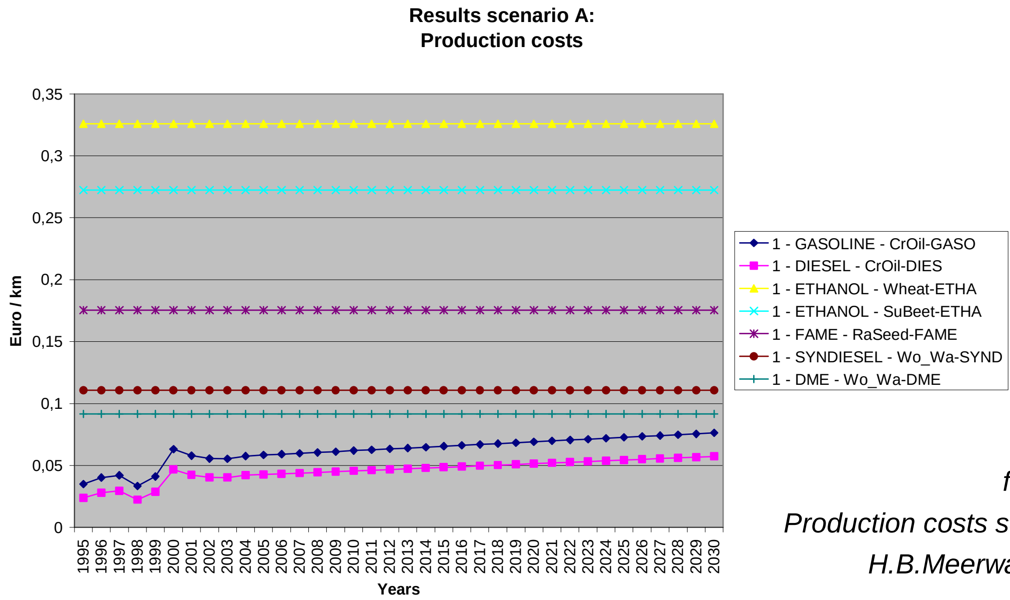

figure 5.1: Production costs scenario A H.B.Meerwaldt, 2005

It can be seen that production costs for fossil fuels rise but remain lower than those for bio fuels.

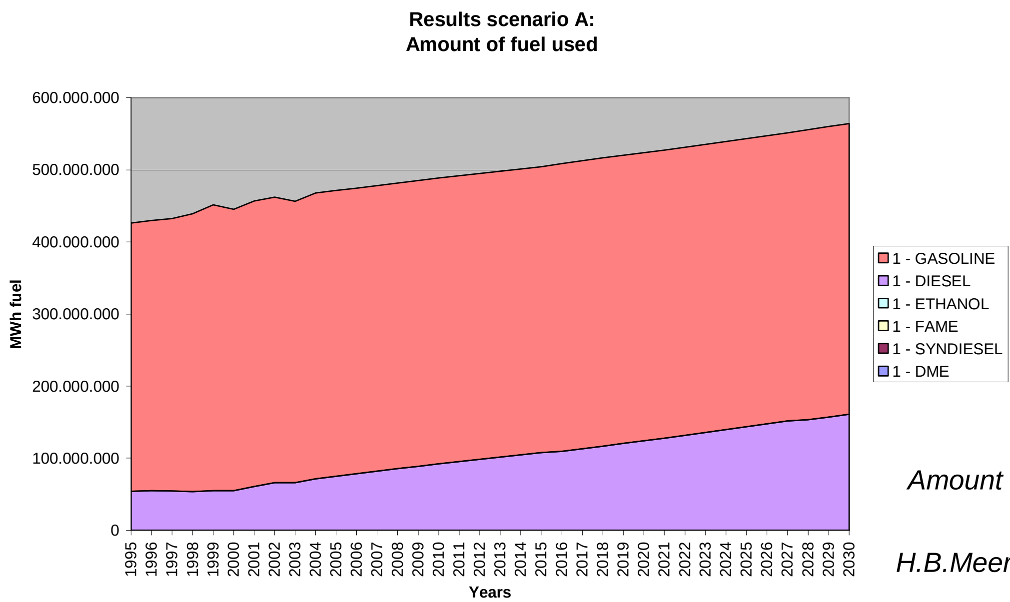

figure 5.2: Amount of fuel used scenario A H.B.Meerwaldt, 2005

Figure 5.2 shows gasoline and diesel are used, but no bio fuel. A table with this data can be found in appendix V.

Scenario B1

In scenario B1 restrictions were made to the amount of fossil fuel used. However, no learning takes place for the production of bio fuels, i.e. LCC = 0 for all bio fuels. Figure 5.3 shows the production costs, figure 5.4 the amount of fuel used.

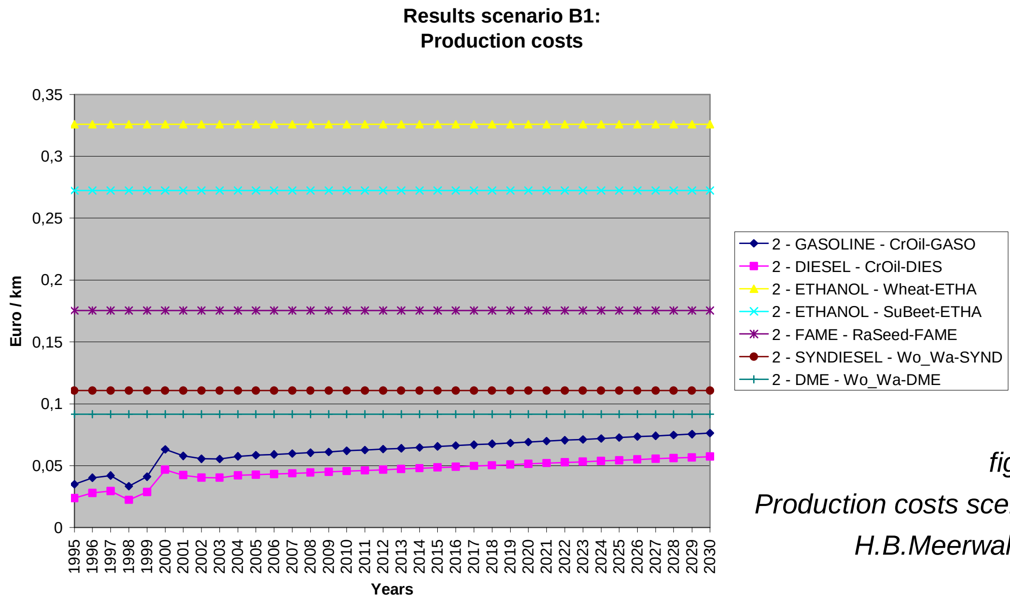

figure 5.3: Production costs scenario B1 H.B.Meerwaldt, 2005

It can be seen that the production prices for gasoline and diesel rise but remain lower than those for the bio fuels.

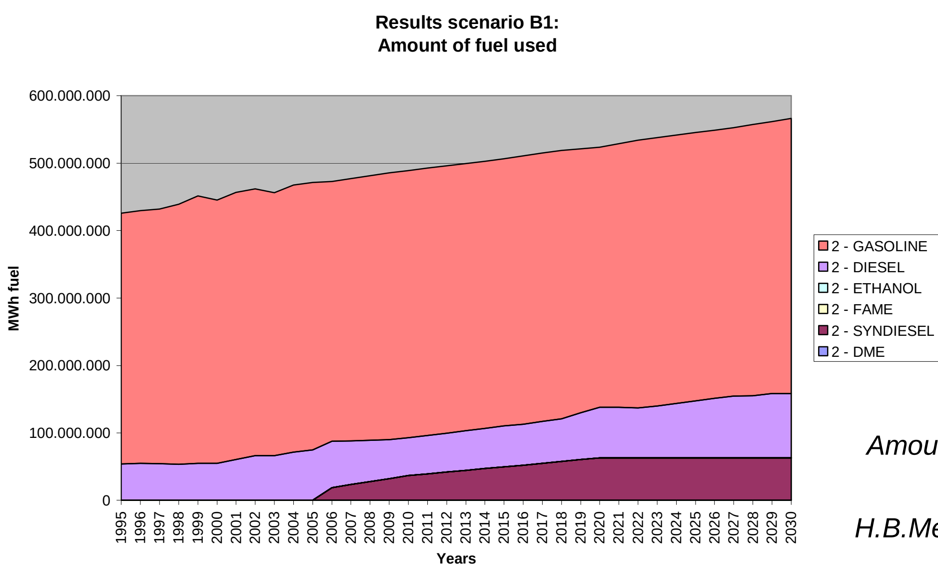

figure 5.4: Amount of fuel used scenario B1 H.B.Meerwaldt, 2005

Figure 5.4 shows gasoline, diesel and syndiesel being used. Inspection of the precise data, which can be found in appendix V, showed that after 2020 the amount of syndiesel used remained at the level of 2020.

Scenario B2

In scenario B2 restrictions were set for the amount of fossil fuel used. Furthermore, the LCCs for all bio fuels were set to -0,3. Figure 5.5 shows the production costs, figure 5.6 the amount of fuel used.

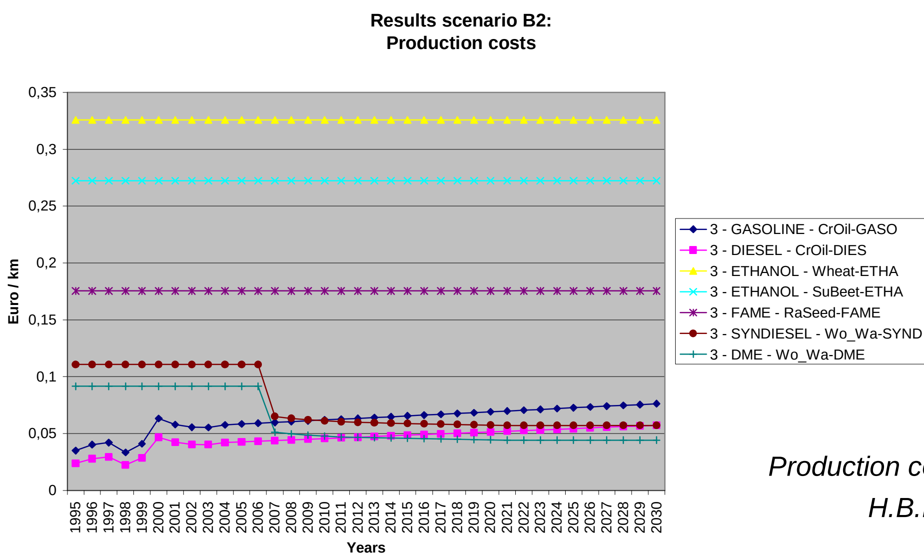

figure 5.5:
Production costs scenario B2
H.B.Meerwaldt, 2005

It can be seen that the production costs for fossil fuels rise and those for syndiesel and DME fall. Production costs for DME are lower than those for gasoline from 2007 on, than those for diesel from 2013 on. Production of syndiesel gets cheaper from 2010 on and arrives at an equal level with diesel in 2029.

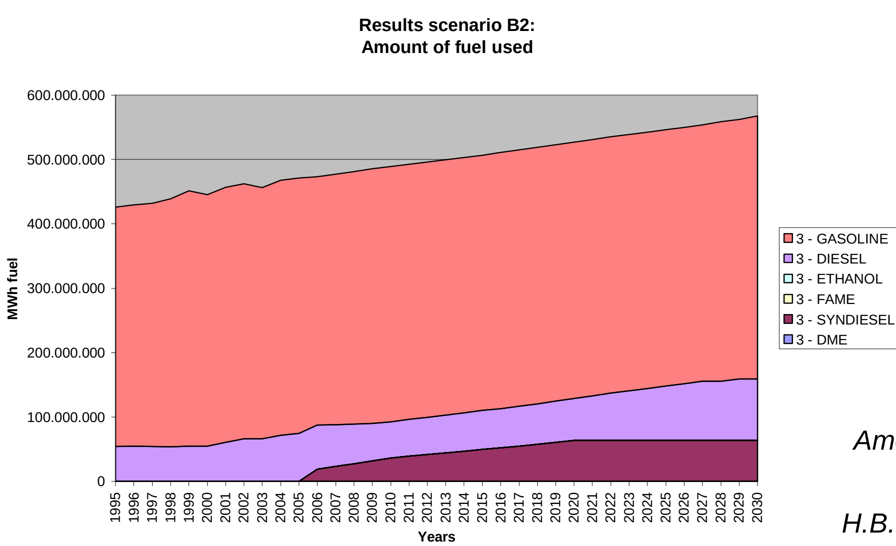

figure 5.6:
Amount of fuel used
scenario B2
H.B.Meerwaldt, 2005

The graph shows that gasoline, diesel and syndiesel were used. When looking at the precise data, to be found in appendix V, it can be seen that the amount of syndiesel used after 2020 remains at the level for 2020.

Scenario B3

In scenario B3 restrictions were set for the amount of fossil fuel used. Also, the LCCs for the bio fuels were set to -0.4. Figure 5.7 shows the production costs, figure 5.8 the amount of fuel used.

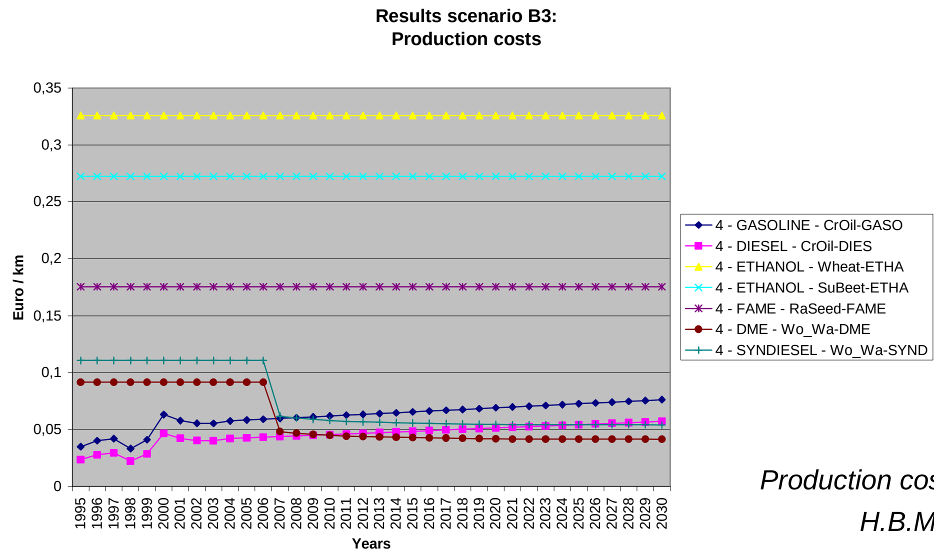

figure 5.7:
Production costs scenario B3
H.B.Meerwaldt, 2005

It can be seen that the production costs for fossil fuels rise and those for syndiesel and DME fall. Production costs for DME are lower than those for gasoline from 2007 on, than those for diesel from 2010 on. Production of syndiesel gets cheaper than that for gasoline from 2009 on and than that for diesel from 2026 on.

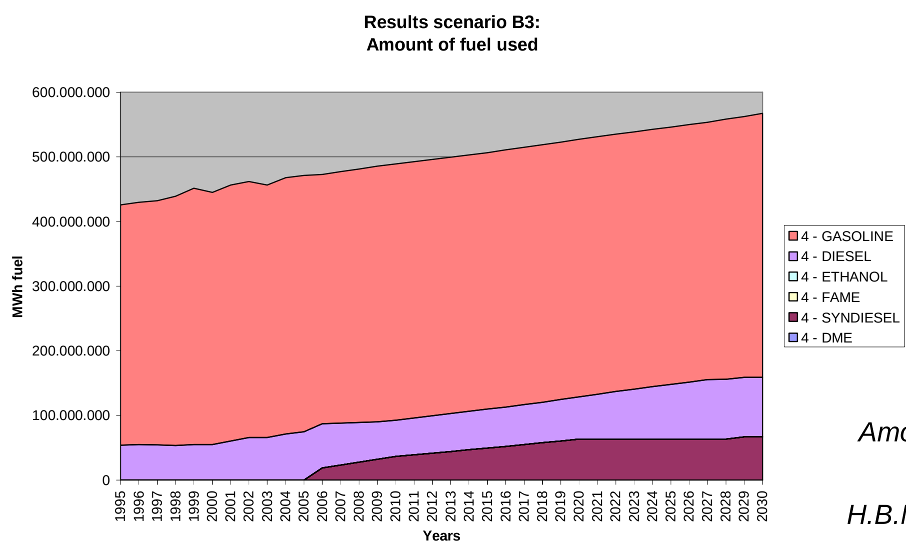

figure 5.8:
Amount of fuel used scenario B3
H.B.Meerwaldt, 2005

Figure 5.8 shows that gasoline, diesel and syndiesel were used. When taking a closer look at the numbers behind this graph, which can be found in appendix V, it can be seen that the amount of syndiesel used after 2020 remains at the level of 2020, until 2029 when the amount starts to rise again.

Scenario B4

In scenario B4 restrictions were set for the amount of gasoline and diesel used. Besides this, the LCCs for all bio fuels were set to -1.0. Figure 5.9 shows the production costs, figure 5.10 the amount of fuel used.

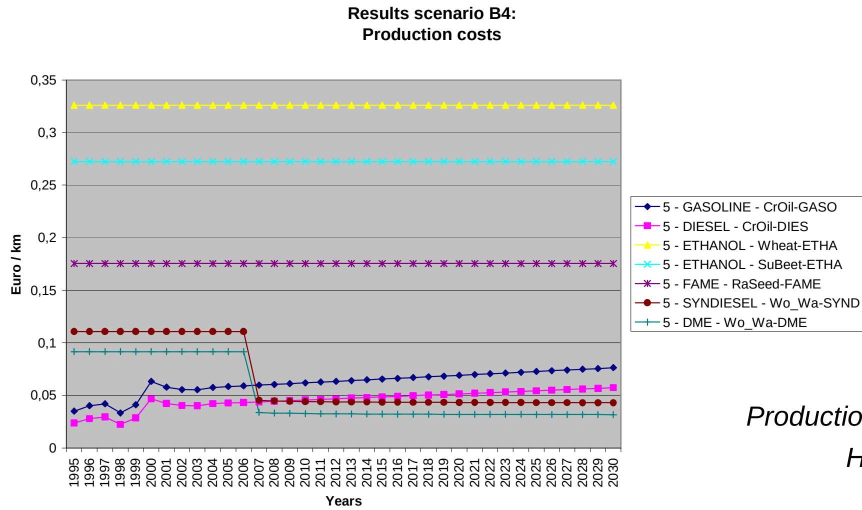

figure 5.9: Production costs scenario B4 H.B.Meerwaldt, 2005

It can be seen that the production costs for fossil fuels rise and those for syndiesel and DME fall. Production costs for DME are lower than those for gasoline from 2007 on, than those for diesel from 2007 on. Production of syndiesel gets cheaper than that for gasoline from 2007 on and than that for diesel from 2009 on.

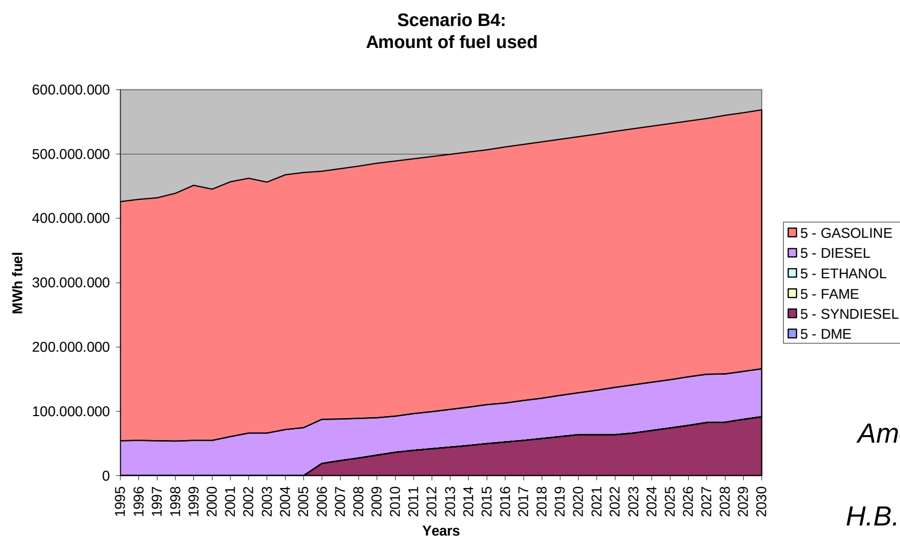

figure 5.10: Amount of fuel used scenario B4 H.B.Meerwaldt, 2005

The graph shows that the fuels gasoline, diesel and syndiesel were used. When precise data is reviewed, which can be found in appendix V, it can be seen that the amount of syndiesel used after 2020 remains at the level for 2020 and starts rising after 2022.

DISCUSSION

Scenario A

In scenario A no restrictions were made concerning the amount of fossil derived fuels used. The results showed no bio fuels being used at all. This means costs for feedstock, production, distribution, refuelling stations and using for all bio fuels are higher than that for the fossil derived fuels. This way no investment in bio fuel production sites were made, so no new capacity was installed. This means no learning took place and the investment costs didn't decrease, which causes this same circle to be followed the next year. No learning and no lock-in took place, meaning the research question cannot be answered using this scenario.

Scenarios B1 & B2

In scenarios B1 and B2 restrictions were made to the amount of fossil derived fuels used. In scenario B1, no learning took place, meaning all LCCs were set to 0. In scenario B2, LCCs were set to -0.35. The results show that the amount of bio fuel, namely syndiesel, used after 2020 in both scenarios remained at the level of 2020. This corresponds to 'output 3' as discussed in the chapter 'Analysis'. After 2020, prices for syndiesel are favourable enough to be used although the constraints are released. When the lifetime of a syndiesel vehicle expires, a new syndiesel one is bought and is not replaced by a gasoline or diesel vehicle. This means the total production capacity for syndiesel keeps on being used. However, without learning or with LCCs of -0.35 investment costs for production have not decreased in such an amount that the production of syndiesel can expand because of rising demand. Looking at the conditions for lock-in,

1. For all years i after 2020: $X_i \geq X_{2020}$
2. For all years i after 2020: $X_{i+1} \geq X_i$
3. For at least one year i after 2020: $X_i > X_{2020}$

we see that condition 3 is not fulfilled; in scenario B1 and in scenario B2 lock-in of bio fuels has not occurred.

Scenarios B3 & B4

In the scenarios B3 and B4, restrictions were set to the amount of fossil derived fuels used. The LCCs for scenario B3 were set at -0.4; those for scenario B4 at -1.0. The results show that for both scenarios after 2020 the amount of syndiesel used rises. In scenario B3 this rising starts in 2029, for scenario B4 in 2023. This corresponds to 'output 5' as described in the chapter 'Analysis'. After 2020, prices for syndiesel have dropped sufficiently to remain at the level of 2020; a terminated syndiesel vehicle is replaced with a new syndiesel vehicle. However, investment costs have not decreased enough to make building new syndiesel production sites cheaper than purchasing gasoline or diesel. This changes in 2029 for scenario B3 and in 2023 for scenario B4. Then, prices for gasoline and diesel have risen in such an amount to make investing in new syndiesel production capacity the most profitable choice. When we look at the conditions for lock-in,

1. For all years i after 2020: $X_i \geq X_{2020}$
2. For all years i after 2020: $X_{i+1} \geq X_i$
3. For at least one year i after 2020: $X_i > X_{2020}$

we see that all three conditions are satisfied for both scenarios; in scenarios B3 and B4 lock-in of bio fuels has occurred.

CONCLUSION

Scenario A showed no use of bio fuels at all. This means no learning and no lock-in too. Scenario B1 and B2 showed to be like 'output 3'; learning was not good enough to lead to lock-in. Scenario B3 and B4 showed to be like 'output 5'; learning was good enough to lead to delayed lock-in. Because of the monoticity of the learning curve in relation to the LCC, it can be concluded that all LCCs between scenario B1 and B2 do not lead to lock-in. All LCCs between scenario B3 and B4 do lead to lock-in. Looking at the research question,

For what rate of learning concerning the production of the bio fuels, ethanol, FAME, syndiesel and DME, does lock-in of these bio fuels occur in Germany, while minimalising overall costs and integrated into an energy system model?

leads to the following conclusion:

Lock-in in Germany of the bio fuel syndiesel occurs for a LCC between -0.35 and -1.0. For the bio fuels ethanol, FAME and DME no amount of fuel is used, let alone that lock-in would occur.

EVALUATION

Product evaluation

The aspect of this research that was least sound was the data used for input. When finding the required data was not possible, assumptions or simplifications were made. The following assumptions were made.

- For the refuelling stations, no data was found for the investment, fixed and variable costs for the different fuels. Instead an estimated guess was made.
- Instead of using a distribution of kilometres in which kilometres were specified per kilometre and vehicle class, a distribution of kilometres per kilometre class and a distribution of vehicle stock per vehicle class were multiplied.
- No data was found for annuities. For this reason estimated guesses were made.
- The values for the LCCs specifying the relation between decrease in costs and cumulative revenue were not found in literature. Instead, these values were used to make different scenarios.
- The values for the LCC2s, specifying the capacity for that technology cluster until current time and relation to foreign learning were not found in literature. Instead, estimates were made.
- Technology clusters were chosen on basis of similarity in the processes they consisted of, not out of patterns in historical data concerning investment costs.
- Formulas to calculate fuel use by vehicles was only found for gasoline and diesel; fuel use for the bio fuels was deduced using proportionality factors, not calculated directly.
- Values for lifetime of vehicles were not found in literature. Instead, assumptions were made.

The following simplifications were made.

- In the model every technology benefits equally from investments made to any technology in the cluster; coupling factors were not used.
- In the whole process of getting the fuels to the customer, learning only takes place in the production phase.
- In the model in the production phase learning has no effect on the feedstock input which would decrease costs per MWh. Instead, learning affects the investment costs (and indirectly the fixed costs) which causes a decrease in the costs per MWh.
- All vehicle classes have the same investment costs.

Process evaluation

During my internship I learned the following things.

- Having physics as my major study, I was used to having all data either given directly or being readily available. In energy studies data isn't handed down on a silver platter and I've learned that you should make a mental network of all sources where you could find data, e.g. web sites of research institutes, the library or search engines for articles. When no data can be found, assumptions have to be made.
- The most important network being one of people. Two know more than one and I've learned that you should ask colleagues or your tutor about where data can be found.
- When you have found a data source, then the most important part comes. I've learned that you should take great care in evaluating and storing data, expanding your network from where data could be found to where data is.
- When doing a three month internship, some days can be frustrating and it can seem like there is still a lot of time left to finish the job. I have learned how to keep myself motivated and going.
- I've learned a lot about the technology behind the production and usage of bio fuels. It increased my enthusiasm for bio fuels.
- Finally, I learned what it is like to work: having your own workplace, responsibilities, a superior, colleagues, going to lunch and having fun.

Policy recommendations

No recommendations for policy can be made; research was about the implications of scenarios on the amount of CO_2eq emitted. No funded recommendation can be made on how to achieve a scenario with a favourable CO_2eq emission.

Suggestions for further research

The following suggestions can be made.

- Researching all motor vehicles, e.g. mopeds, motor cycles, LCVs, trucks or buses.
- Implementing learning curves in more phases.
- Implementing optimalisation over multiple years instead of over one year, making long term projects more favourable.
- Implementing more technologies for production, distribution and refuelling stations.

- Implementing mixture of bio fuels into fossil fuels.
- Implementing other (bio) fuels, e.g. CNG, methanol or hydrogen.
- Researching more countries.
- Implementing more regions and areas in Germany to reach a more geographical distribution.
- Implementing domestic feedstock production.
- Connecting the model directly with the electricity and heat sector to analyze the competition and the possible cluster learning effects.

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APPENDICES

Appendix I

Variable costs for crude oil, import prices for gasoline and diesel for each year

Year	Feedstock Var. costs crude oil € / MWh	Import Var. costs gasoline € / MWh	Import Var. costs diesel € / MWh
1995	8,01	11,34	9,83
1996	10,03	15,39	12,62
1997	10,79	17,21	13,72
1998	7,33	11,75	10,16
1999	10,37	13,41	11,10
2000	19,14	26,57	25,07
2001	17,03	23,83	22,11
2002	16,10	22,18	19,48
2003	16,02	23,01	19,99
2004	15,49	21,09	19,12
2005	14,99	20,59	18,61
2006	14,50	20,11	18,12
2007	14,02	19,65	17,64
2008	13,57	19,20	17,18
2009	13,12	18,76	16,73
2010	12,69	18,34	16,30
2011	12,91	18,56	16,52
2012	13,14	18,78	16,75
2013	13,37	19,00	16,98
2014	13,60	19,23	17,21
2015	13,84	19,46	17,45
2016	14,08	19,70	17,69
2017	14,32	19,94	17,94
2018	14,57	20,18	18,19
2019	14,82	20,43	18,44
2020	15,08	20,69	18,70
2021	15,32	20,92	18,94
2022	15,57	21,16	19,19
2023	15,81	21,40	19,44
2024	16,06	21,65	19,69
2025	16,32	21,90	19,95
2026	16,58	22,16	20,21
2027	16,84	22,42	20,47
2028	17,11	22,68	20,74
2029	17,38	22,95	21,02

Appendix II

Efficiencies for vehicles

Fuel	Cylinder capacity	Usage Efficiency MWh / km
Gasoline	0 – 1.4 l	0.000682
	1.4 – 2.0 l	0.000844
	2.0 l +	0.000981
Diesel	0 – 1.4 l	0.000679
	1.4 – 2.0 l	0.000679
	2.0 l +	0.000679
Ethanol	0 – 1.4 l	0.000682
	1.4 – 2.0 l	0.000844
	2.0 l +	0.000981
FAME	0 – 1.4 l	0.000679
	1.4 – 2.0 l	0.000679
	2.0 l +	0.000679
Syndiesel	0 – 1.4 l	0.000679
	1.4 – 2.0 l	0.000679
	2.0 l +	0.000679
DME	0 – 1.4 l	0.000679
	1.4 – 2.0 l	0.000679
	2.0 l +	0.000679

Appendix III

Kilometre demand for Germany for each year

Year a	Demand km / a	Year a	Demand km / a	Year a	Demand km / a	Year a	Demand km / a
1995	5.35E+11	2004	5.90E+11	2013	6.47E+11	2022	7.04E+11
1996	5.40E+11	2005	5.97E+11	2014	6.53E+11	2023	7.10E+11
1997	5.43E+11	2006	6.03E+11	2015	6.60E+11	2024	7.16E+11
1998	5.51E+11	2007	6.09E+11	2016	6.66E+11	2025	7.23E+11
1999	5.66E+11	2008	6.16E+11	2017	6.72E+11	2026	7.29E+11
2000	5.60E+11	2009	6.22E+11	2018	6.78E+11	2027	7.35E+11
2001	5.76E+11	2010	6.28E+11	2019	6.85E+11	2028	7.41E+11
2002	5.84E+11	2011	6.34E+11	2020	6.91E+11	2029	7.48E+11
2003	5.78E+11	2012	6.41E+11	2021	6.97E+11	2030	7.54E+11

Appendix IV

Historical number of gasoline vehicles in Germany with a cylinder capacity of 0 – 1.4 l

Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.
1995	1,03E+07	2004	1,00E+07	2013	1,83E+06	2022	0,00E+00
1996	1,05E+07	2005	9,13E+06	2014	9,13E+05	2023	0,00E+00
1997	1,06E+07	2006	8,22E+06	2015	0,00E+00	2024	0,00E+00
1998	1,07E+07	2007	7,31E+06	2016	0,00E+00	2025	0,00E+00
1999	1,09E+07	2008	6,39E+06	2017	0,00E+00	2026	0,00E+00
2000	1,09E+07	2009	5,48E+06	2018	0,00E+00	2027	0,00E+00
2001	1,11E+07	2010	4,57E+06	2019	0,00E+00	2028	0,00E+00
2002	1,10E+07	2011	3,65E+06	2020	0,00E+00	2029	0,00E+00
2003	1,10E+07	2012	2,74E+06	2021	0,00E+00	2030	0,00E+00

Historical number of gasoline vehicles in Germany with a cylinder capacity of 1.4 – 2.0 l

Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.
1995	1,92E+07	2004	1,87E+07	2013	3,40E+06	2022	0,00E+00
1996	1,95E+07	2005	1,70E+07	2014	1,70E+06	2023	0,00E+00
1997	1,97E+07	2006	1,53E+07	2015	0,00E+00	2024	0,00E+00
1998	2,00E+07	2007	1,36E+07	2016	0,00E+00	2025	0,00E+00
1999	2,02E+07	2008	1,19E+07	2017	0,00E+00	2026	0,00E+00
2000	2,03E+07	2009	1,02E+07	2018	0,00E+00	2027	0,00E+00
2001	2,07E+07	2010	8,50E+06	2019	0,00E+00	2028	0,00E+00
2002	2,05E+07	2011	6,80E+06	2020	0,00E+00	2029	0,00E+00
2003	2,04E+07	2012	5,10E+06	2021	0,00E+00	2030	0,00E+00

Historical number of gasoline vehicles in Germany with a cylinder capacity of 2.0 l +

Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.
1995	5,33E+06	2004	5,19E+06	2013	9,44E+05	2022	0,00E+00
1996	5,41E+06	2005	4,72E+06	2014	4,72E+05	2023	0,00E+00
1997	5,47E+06	2006	4,25E+06	2015	0,00E+00	2024	0,00E+00
1998	5,55E+06	2007	3,78E+06	2016	0,00E+00	2025	0,00E+00
1999	5,62E+06	2008	3,30E+06	2017	0,00E+00	2026	0,00E+00
2000	5,65E+06	2009	2,83E+06	2018	0,00E+00	2027	0,00E+00
2001	5,74E+06	2010	2,36E+06	2019	0,00E+00	2028	0,00E+00
2002	5,69E+06	2011	1,89E+06	2020	0,00E+00	2029	0,00E+00
2003	5,66E+06	2012	1,42E+06	2021	0,00E+00	2030	0,00E+00

Historical number of diesel vehicles in Germany with a cylinder capacity of 0 – 1.4 l

Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.
1995	1,64E+06	2004	2,16E+06	2013	3,93E+05	2022	0,00E+00
1996	1,67E+06	2005	1,97E+06	2014	1,97E+05	2023	0,00E+00
1997	1,65E+06	2006	1,77E+06	2015	0,00E+00	2024	0,00E+00
1998	1,62E+06	2007	1,57E+06	2016	0,00E+00	2025	0,00E+00
1999	1,67E+06	2008	1,38E+06	2017	0,00E+00	2026	0,00E+00
2000	1,76E+06	2009	1,18E+06	2018	0,00E+00	2027	0,00E+00
2001	1,98E+06	2010	9,84E+05	2019	0,00E+00	2028	0,00E+00
2002	2,17E+06	2011	7,87E+05	2020	0,00E+00	2029	0,00E+00
2003	2,36E+06	2012	5,90E+05	2021	0,00E+00	2030	0,00E+00

Historical number of diesel vehicles in Germany with a cylinder capacity of 1.4 – 2.0 l

Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.
1995	3,05E+06	2004	4,03E+06	2013	7,32E+05	2022	0,00E+00
1996	3,11E+06	2005	3,66E+06	2014	3,66E+05	2023	0,00E+00
1997	3,07E+06	2006	3,30E+06	2015	0,00E+00	2024	0,00E+00
1998	3,02E+06	2007	2,93E+06	2016	0,00E+00	2025	0,00E+00
1999	3,11E+06	2008	2,56E+06	2017	0,00E+00	2026	0,00E+00
2000	3,28E+06	2009	2,20E+06	2018	0,00E+00	2027	0,00E+00
2001	3,69E+06	2010	1,83E+06	2019	0,00E+00	2028	0,00E+00
2002	4,03E+06	2011	1,46E+06	2020	0,00E+00	2029	0,00E+00
2003	4,39E+06	2012	1,10E+06	2021	0,00E+00	2030	0,00E+00

Historical number of diesel vehicles in Germany with a cylinder capacity of 2.0 l +

Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.	Year a	Number of veh.
1995	8,48E+05	2004	1,12E+06	2013	2,03E+05	2022	0,00E+00
1996	8,63E+05	2005	1,02E+06	2014	1,02E+05	2023	0,00E+00
1997	8,53E+05	2006	9,15E+05	2015	0,00E+00	2024	0,00E+00
1998	8,38E+05	2007	8,14E+05	2016	0,00E+00	2025	0,00E+00
1999	8,63E+05	2008	7,12E+05	2017	0,00E+00	2026	0,00E+00
2000	9,10E+05	2009	6,10E+05	2018	0,00E+00	2027	0,00E+00
2001	1,02E+06	2010	5,08E+05	2019	0,00E+00	2028	0,00E+00
2002	1,12E+06	2011	4,07E+05	2020	0,00E+00	2029	0,00E+00
2003	1,22E+06	2012	3,05E+05	2021	0,00E+00	2030	0,00E+00

Appendix V

Amount of fuel used in scenario A

years	gasoline MWh	diesel MWh	ethanol MWh	FAME MWh	syndiesel MWh	DME MWh
1995	3,72E+08	5,41E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1996	3,74E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1997	3,78E+08	5,44E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1998	3,86E+08	5,35E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1999	3,96E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2000	3,90E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2001	3,96E+08	6,06E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2002	3,96E+08	6,60E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2003	3,90E+08	6,60E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2004	3,96E+08	7,14E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2005	3,96E+08	7,49E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2006	3,96E+08	7,84E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2007	3,96E+08	8,19E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2008	3,96E+08	8,54E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2009	3,96E+08	8,88E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2010	3,96E+08	9,23E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2011	3,96E+08	9,54E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2012	3,96E+08	9,86E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2013	3,96E+08	1,02E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2014	3,96E+08	1,05E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2015	3,96E+08	1,08E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2016	3,99E+08	1,09E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2017	3,99E+08	1,13E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2018	3,99E+08	1,17E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2019	3,99E+08	1,21E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2020	3,99E+08	1,24E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2021	3,99E+08	1,28E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2022	3,99E+08	1,32E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2023	3,99E+08	1,36E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2024	3,99E+08	1,40E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2025	3,99E+08	1,44E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2026	3,99E+08	1,48E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2027	3,99E+08	1,52E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2028	4,03E+08	1,53E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2029	4,03E+08	1,57E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2030	4,03E+08	1,61E+08	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Amount of fuel used in scenario B1

years	gasoline MWh	diesel MWh	ethanol MWh	FAME MWh	syndiesel MWh	DME MWh
1995	3,72E+08	5,41E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1996	3,74E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1997	3,78E+08	5,44E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1998	3,86E+08	5,35E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1999	3,96E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2000	3,90E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2001	3,96E+08	6,06E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2002	3,96E+08	6,60E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2003	3,90E+08	6,60E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2004	3,96E+08	7,14E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2005	3,96E+08	7,49E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2006	3,86E+08	6,84E+07	0,00E+00	0,00E+00	1,89E+07	0,00E+00
2007	3,89E+08	6,50E+07	0,00E+00	0,00E+00	2,33E+07	0,00E+00
2008	3,92E+08	6,15E+07	0,00E+00	0,00E+00	2,77E+07	0,00E+00
2009	3,95E+08	5,80E+07	0,00E+00	0,00E+00	3,22E+07	0,00E+00
2010	3,96E+08	5,60E+07	0,00E+00	0,00E+00	3,67E+07	0,00E+00
2011	3,96E+08	5,70E+07	0,00E+00	0,00E+00	3,92E+07	0,00E+00
2012	3,96E+08	5,80E+07	0,00E+00	0,00E+00	4,17E+07	0,00E+00
2013	3,96E+08	5,89E+07	0,00E+00	0,00E+00	4,43E+07	0,00E+00
2014	3,96E+08	5,98E+07	0,00E+00	0,00E+00	4,69E+07	0,00E+00
2015	3,96E+08	6,06E+07	0,00E+00	0,00E+00	4,95E+07	0,00E+00
2016	3,98E+08	6,06E+07	0,00E+00	0,00E+00	5,23E+07	0,00E+00
2017	3,98E+08	6,19E+07	0,00E+00	0,00E+00	5,50E+07	0,00E+00
2018	3,98E+08	6,29E+07	0,00E+00	0,00E+00	5,78E+07	0,00E+00
2019	3,91E+08	6,93E+07	0,00E+00	0,00E+00	6,04E+07	0,00E+00
2020	3,86E+08	7,49E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00
2021	3,91E+08	7,49E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00
2022	3,97E+08	7,40E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00
2023	3,98E+08	7,68E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00
2024	3,98E+08	8,05E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00
2025	3,98E+08	8,42E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00
2026	3,98E+08	8,79E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00
2027	3,98E+08	9,16E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00
2028	4,03E+08	9,19E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00
2029	4,03E+08	9,53E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00
2030	4,08E+08	9,53E+07	0,00E+00	0,00E+00	6,31E+07	0,00E+00

Amount of fuel used in scenario B2

years	gasoline MWh	diesel MWh	ethanol MWh	FAME MWh	syndiesel MWh	DME MWh
1995	3,72E+08	5,41E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1996	3,74E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1997	3,78E+08	5,44E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1998	3,86E+08	5,35E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1999	3,96E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2000	3,90E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2001	3,96E+08	6,06E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2002	3,96E+08	6,60E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2003	3,90E+08	6,60E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2004	3,96E+08	7,14E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2005	3,96E+08	7,49E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2006	3,86E+08	6,84E+07	0,00E+00	0,00E+00	1,89E+07	0,00E+00
2007	3,89E+08	6,50E+07	0,00E+00	0,00E+00	2,33E+07	0,00E+00
2008	3,92E+08	6,15E+07	0,00E+00	0,00E+00	2,77E+07	0,00E+00
2009	3,95E+08	5,80E+07	0,00E+00	0,00E+00	3,22E+07	0,00E+00
2010	3,96E+08	5,60E+07	0,00E+00	0,00E+00	3,67E+07	0,00E+00
2011	3,96E+08	5,70E+07	0,00E+00	0,00E+00	3,92E+07	0,00E+00
2012	3,96E+08	5,80E+07	0,00E+00	0,00E+00	4,17E+07	0,00E+00
2013	3,96E+08	5,89E+07	0,00E+00	0,00E+00	4,43E+07	0,00E+00
2014	3,96E+08	5,98E+07	0,00E+00	0,00E+00	4,69E+07	0,00E+00
2015	3,96E+08	6,06E+07	0,00E+00	0,00E+00	4,95E+07	0,00E+00
2016	3,98E+08	6,06E+07	0,00E+00	0,00E+00	5,23E+07	0,00E+00
2017	3,98E+08	6,19E+07	0,00E+00	0,00E+00	5,50E+07	0,00E+00
2018	3,98E+08	6,29E+07	0,00E+00	0,00E+00	5,78E+07	0,00E+00
2019	3,98E+08	6,42E+07	0,00E+00	0,00E+00	6,06E+07	0,00E+00
2020	3,98E+08	6,54E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2021	3,98E+08	6,95E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2022	3,98E+08	7,36E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2023	3,98E+08	7,73E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2024	3,98E+08	8,09E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2025	3,98E+08	8,46E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2026	3,98E+08	8,83E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2027	3,98E+08	9,20E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2028	4,03E+08	9,23E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2029	4,03E+08	9,57E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2030	4,08E+08	9,57E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00

Amount of fuel used in scenario B3

years	gasoline MWh	diesel MWh	ethanol MWh	FAME MWh	syndiesel MWh	DME MWh
1995	3,72E+08	5,41E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1996	3,74E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1997	3,78E+08	5,44E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1998	3,86E+08	5,35E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1999	3,96E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2000	3,90E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2001	3,96E+08	6,06E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2002	3,96E+08	6,60E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2003	3,90E+08	6,60E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2004	3,96E+08	7,14E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2005	3,96E+08	7,49E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2006	3,86E+08	6,84E+07	0,00E+00	0,00E+00	1,89E+07	0,00E+00
2007	3,89E+08	6,50E+07	0,00E+00	0,00E+00	2,33E+07	0,00E+00
2008	3,92E+08	6,15E+07	0,00E+00	0,00E+00	2,77E+07	0,00E+00
2009	3,95E+08	5,80E+07	0,00E+00	0,00E+00	3,22E+07	0,00E+00
2010	3,96E+08	5,60E+07	0,00E+00	0,00E+00	3,67E+07	0,00E+00
2011	3,96E+08	5,70E+07	0,00E+00	0,00E+00	3,92E+07	0,00E+00
2012	3,96E+08	5,80E+07	0,00E+00	0,00E+00	4,17E+07	0,00E+00
2013	3,96E+08	5,89E+07	0,00E+00	0,00E+00	4,43E+07	0,00E+00
2014	3,96E+08	5,98E+07	0,00E+00	0,00E+00	4,69E+07	0,00E+00
2015	3,96E+08	6,06E+07	0,00E+00	0,00E+00	4,95E+07	0,00E+00
2016	3,98E+08	6,06E+07	0,00E+00	0,00E+00	5,23E+07	0,00E+00
2017	3,98E+08	6,19E+07	0,00E+00	0,00E+00	5,50E+07	0,00E+00
2018	3,98E+08	6,29E+07	0,00E+00	0,00E+00	5,78E+07	0,00E+00
2019	3,98E+08	6,42E+07	0,00E+00	0,00E+00	6,06E+07	0,00E+00
2020	3,98E+08	6,54E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2021	3,98E+08	6,95E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2022	3,98E+08	7,36E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2023	3,98E+08	7,73E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2024	3,98E+08	8,09E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2025	3,98E+08	8,46E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2026	3,98E+08	8,83E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2027	3,98E+08	9,20E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2028	4,03E+08	9,23E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2029	4,03E+08	9,23E+07	0,00E+00	0,00E+00	6,68E+07	0,00E+00
2030	4,08E+08	9,23E+07	0,00E+00	0,00E+00	6,68E+07	0,00E+00

Amount of fuel used in scenario B4

years	gasoline MWh	diesel MWh	ethanol MWh	FAME MWh	syndiesel MWh	DME MWh
1995	3,72E+08	5,41E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1996	3,74E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1997	3,78E+08	5,44E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1998	3,86E+08	5,35E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
1999	3,96E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2000	3,90E+08	5,51E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2001	3,96E+08	6,06E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2002	3,96E+08	6,60E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2003	3,90E+08	6,60E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2004	3,96E+08	7,14E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2005	3,96E+08	7,49E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00
2006	3,86E+08	6,84E+07	0,00E+00	0,00E+00	1,89E+07	0,00E+00
2007	3,89E+08	6,50E+07	0,00E+00	0,00E+00	2,33E+07	0,00E+00
2008	3,92E+08	6,15E+07	0,00E+00	0,00E+00	2,77E+07	0,00E+00
2009	3,95E+08	5,80E+07	0,00E+00	0,00E+00	3,22E+07	0,00E+00
2010	3,96E+08	5,60E+07	0,00E+00	0,00E+00	3,67E+07	0,00E+00
2011	3,96E+08	5,70E+07	0,00E+00	0,00E+00	3,92E+07	0,00E+00
2012	3,96E+08	5,80E+07	0,00E+00	0,00E+00	4,17E+07	0,00E+00
2013	3,96E+08	5,89E+07	0,00E+00	0,00E+00	4,43E+07	0,00E+00
2014	3,96E+08	5,98E+07	0,00E+00	0,00E+00	4,69E+07	0,00E+00
2015	3,96E+08	6,06E+07	0,00E+00	0,00E+00	4,95E+07	0,00E+00
2016	3,98E+08	6,06E+07	0,00E+00	0,00E+00	5,23E+07	0,00E+00
2017	3,98E+08	6,19E+07	0,00E+00	0,00E+00	5,50E+07	0,00E+00
2018	3,98E+08	6,29E+07	0,00E+00	0,00E+00	5,78E+07	0,00E+00
2019	3,98E+08	6,42E+07	0,00E+00	0,00E+00	6,06E+07	0,00E+00
2020	3,98E+08	6,54E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2021	3,98E+08	6,95E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2022	3,98E+08	7,36E+07	0,00E+00	0,00E+00	6,35E+07	0,00E+00
2023	3,98E+08	7,49E+07	0,00E+00	0,00E+00	6,62E+07	0,00E+00
2024	3,98E+08	7,49E+07	0,00E+00	0,00E+00	7,03E+07	0,00E+00
2025	3,98E+08	7,49E+07	0,00E+00	0,00E+00	7,44E+07	0,00E+00
2026	3,98E+08	7,49E+07	0,00E+00	0,00E+00	7,84E+07	0,00E+00
2027	3,98E+08	7,49E+07	0,00E+00	0,00E+00	8,25E+07	0,00E+00
2028	4,02E+08	7,49E+07	0,00E+00	0,00E+00	8,34E+07	0,00E+00
2029	4,02E+08	7,49E+07	0,00E+00	0,00E+00	8,72E+07	0,00E+00
2030	4,02E+08	7,49E+07	0,00E+00	0,00E+00	9,13E+07	0,00E+00