649342 EUFORIE

European Futures for Energy Efficiency

LINDA models: baseline and energy efficiency scenarios for the EU-28 Member States

WP2 Deliverable D2.3 and Deliverable D2.4

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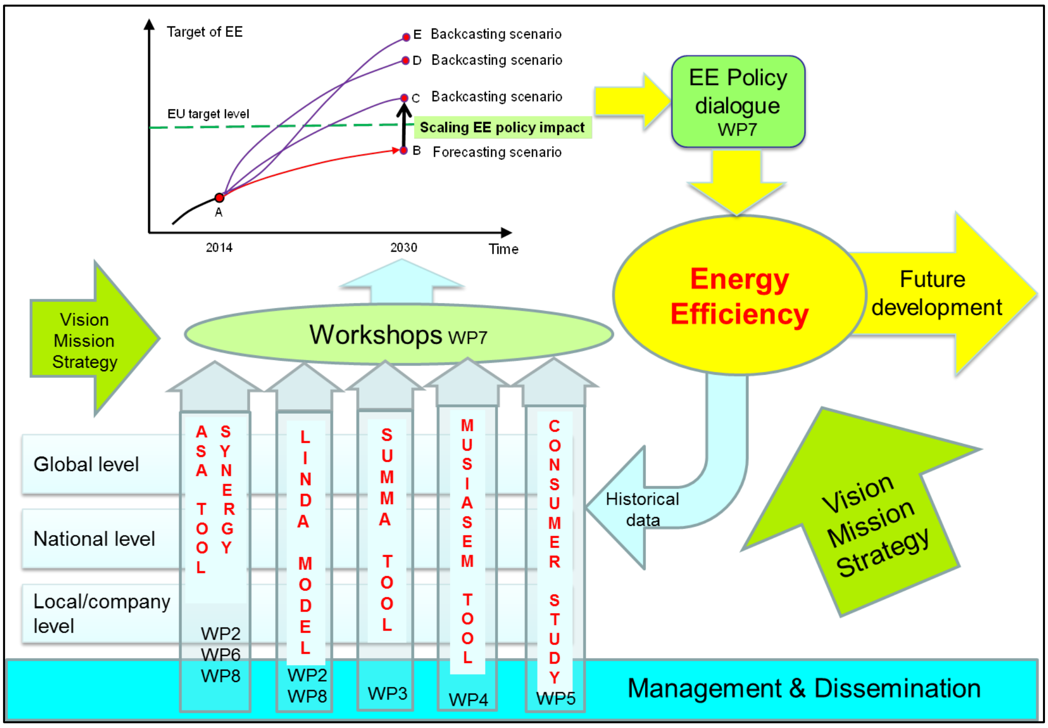
The EUFORIE project

The strategic goal of the EUFORIE project is to provide useful and accurate information and knowledge in the field of energy efficiency for the EU Commission and stakeholders in the Member States. The tangible objectives are the following:

1. To provide energy and energy efficiency trends and their drivers, synergies and trade-offs between energy efficiency related policies, as well as energy efficiency scenarios (WP2).
2. To provide data about implementation of energy efficiency in specific processes, sectors and entire systems, in order to understand bottlenecks/efficiency drops and suggest improvements (WP3).
3. To carry out analyses of efficiency of provision, from making useful energy carriers from primary energy sources, and from conversion of energy carriers to end uses across macro-economic sectors (WP4).
4. To identify policy instruments and other measures leading to significant reduction in the energy consumption of households (WP5).
5. To analyse the relationship between investments and change in energy efficiency, and to develop indicators to describe changing energy efficiency at the company level (WP6).
6. To carry out participatory foresight for European stakeholders of energy efficiency with a target of providing ideas for the energy efficiency vision and strategy in the European Union (WP7).
7. To compare energy efficiency policy instruments and measures and their impacts in China and the European Union (WP8).

The EUFORIE Work Packages relate to each other. The project applies different quantitative and qualitative analysis methods to energy efficiency in the EU and its Member States at different levels and from different perspectives. These analyses provide input for foresight activities, which serve European energy efficiency vision and strategy process by generating useful information. Management (WP1) and dissemination (WP9) run in parallel with the research and innovation activities.



Executive summary

The purpose of this deliverable is to construct energy scenarios for the European Union and for individual Member States, and evaluate how the adopted energy efficiency related policy targets for the year 2030 could be achieved at the Community level. This is done by using the LINDA (Long Range Integrated Development Analysis) modeling approach developed in University of Turku, Finland Futures Research Centre.

The LINDA modeling approach is based on data accounting and the model builds on the drivers of CO_2 emissions identified in an extended Kaya identity.

$$CO2 = \frac{CO2}{TPES} \times \frac{TPES}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{POP} \times POP$$

where TPES is total primary energy supply, FEC is final energy consumption, GDP is gross domestic product in real/fixed prices, and POP is the amount of population. LINDA models are suitable for projecting the use of fuels and electricity, total primary energy use, and CO_2 emissions from fossil fuel combustion in different economic sectors. The projections, called also as LINDA scenarios, are results of the modeling. The different results are based on user-defined assumptions on:

- changing fuel mix in different sectors of the economy,
- expansion of economic activity in different economic sectors (as annual change rates of sectoral value added/share of GDP),
- annual changes in electricity and fuel use intensities (change rates per unit of generated value added/share of GDP),
- change in residential use of fuels and electricity,
- change in population growth, and
- changes in power plant capacity.

LINDA models the energy production side at high level, and the consumption side at relatively low level based on intensity trends. The LINDA models are well suitable for

- investigating how different schedules for transitions in fuel use and electricity production play out in terms of CO_2 emissions
- how different investment plans for power plant capacity will cover the electricity need of the system when different economic developments are assumed, and
- how different scenarios for energy efficiency will influence the use of fuels and electricity, and the need of new power plant capacity, as well as reaching CO_2 emission targets.

In the EUFORIE project, LINDA models have been constructed for 24 individual European countries, of which 21 are EU Member States, and for the EU aggregate covering all the 28 Member States. A LINDA model for China is also available. All the LINDA models constructed in the EUFORIE project and the user instructions can be downloaded from the project website, www.euforie-h2020.eu.The models are country-specific MS Excel files. A more detailed description of the model is included in this deliverable.

The data used in the models is collected from various data sources, such as International Energy Agency (electricity, fuel, and CO_2 emission data), World Bank (economic data), United Nations (population data), EU DG ENER (power plant data), and ODYSSEE-MURE database (data of the transport sector).

The results include different energy efficiency projections for the EU-28 as a whole, and for selected EU Member States (Finland, Germany, Italy and Spain). The baseline scenario for the EU-28 as a whole is based on historical trends of energy use and economic growth and on output of other modeling efforts resulting in the EU Reference Scenario 2016. This baseline scenario gives an answer to the question “Where will the expected/assumed energy efficiency trends lead the EU and its Member States by the year 2030?” Second, four different energy efficiency scenarios are derived from the baseline scenario by changing the input. The substance of these projections is to give different answers to the question “How the existing energy efficiency targets of the EU and its 28 Member States can be reached?” The table below presents the scenario results in relation to the EU targets. Finally, the baseline and energy efficiency scenarios are presented for selected EU Member States, i.e. for Finland, Germany, Italy, and Spain. For these Member States, additional industry-driven scenarios are presented for comparison. The 2030 targets for individual EU Member States are not available yet.

Summary of the LINDA EU-28 scenarios in terms of EU 2030 energy policy targets.

Indicator	**EU target 2030**	**LINDA EU-28 scenario**				
		Baseline 2030	*EFF1 2030 higher efficiency*	*EFF2 2030 lower efficiency*	*EFF3 2030 (EFF2 + comer-cial growth)*	*EFF4 2030 (EFF2 + indus-trial growth)*
Final energy consumption	-17 % from 2005	-12.1 %	-28.0 %	-20.9 %	-21.7 %	-16.0 %
Total primary energy supply	-23 % from 2005	-9.5 %	-25.5 %	-20,3 %	-20.9 %	-16.7 %
CO_2 emissions	-40 % from 1990	-35.9 %	-46.7 %	-44.0 %	-44.1 %	-42.2 %
Share of renewables	share 27 %	23.1 %	23.6 %	23.8 %	23.8 %	24.0 %

Based on these scenarios and their evaluation, major conclusion is that the renewable energy target is the most challenging among the energy-related policy targets adopted at the EU Community level for the year 2030. Targets of energy efficiency (primary and final energy consumption) and the CO_2 emission targets are less challenging at the Community level. However, differences between the individual Member States are large.

The LINDA models are valuable for all stakeholders interested in playing with energy scenarios and seeing how a change in the user-defined assumptions such as economic growth or energy intensity in different sectors of the economy, affects energy use and CO_2 emissions at the macro level. The LINDA modeling approach is useful in energy policy planning and scenario construction at the Community and Member State levels. The models are useful also for researchers who are willing to develop the model by adding more and more detailed information, and applying the LINDA modeling approach in other countries.

Tasks of this deliverable related to WP2

This deliverable is a combination of two EUFORIE WP2 deliverables: D2.3 (EUROLINDA models and baseline scenarios for EU-28 Member States) and D2.4 (Energy efficiency scenarios). It covers the following WP2 tasks:

- Task 2.3 "EuroLinda model construction for EU-28 Member States", and
- Task 2.4 "Energy efficiency scenarios".

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Abbreviations

Abbreviation	Explanation
BAU	Business as usual (scenario)
CO_2	Carbon dioxide (emissions)
EC	European Commission
EFF	Efficiency (Energy efficiency scenario)
EU	European Union
EUFORIE	European Futures for Energy Efficiency
FEC	Final energy consumption
GDP	Gross Domestic Product
GHG	Greenhouse gases (emissions)
IEA	International Energy Agency
IND	Industrial (scenario)
kWh	kilowatt-hour
LINDA	Long-range integrated development analysis
Mtoe	Million tonnes of oil equivalent
NEEAP	National energy efficiency action plan
POP	(Amount of) Population
TPES	Total primary energy supply
UN	United Nations
USD, US$	United States dollars
VA	Value added
VBA	Visual Basics
WP	Work Package

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Goals of this deliverable

This EUFORIE deliverable D2.3 & D2.4 has three main goals:

1. to give an overview of the LINDA modeling approach and brief instructions to the use of the LINDA models,
2. to construct baseline scenarios (by assuming a continuation of historical trends of the main drivers) and energy efficiency scenarios (by changing assumptions favouring energy efficiency) for the EU as a whole and for selected EU Member States, and
3. to evaluate the constructed scenarios from the point of view the adopted 2030 targets dealing with energy efficiency and other energy/related issues at the community (EU-28) level.

Introduction

Energy efficiency is a means to tackle energy-related negative impacts such as emissions in the air, but in the policy arena it has gained a status of a target even as such. Energy efficiency can be improved in energy production and consumption, and there are many technologies and policy instruments available (see Future Energy 2017; ODYSSEE-MURE 2017, for example). Based on the EU directive on energy efficiency (European Commission 2012), the Member States prepare their National Energy Efficiency Action Plans (NEEAPs), where they set out the estimated energy consumption, planned energy efficiency measures, and the improvements they expect to achieve. The Member States report their achievements in the Annual Reports.

The energy efficiency target and other EU targets that are the focal point of the scenario study reported in this document are derived from the European Commission 2030 climate and energy framework (European Commission 2017b) and the EU reference scenario 2016 (European Commission 2016a). The EU reference scenario 2016 is developed by a consortium led by the National Technical University of Athens. It uses a set of models responsible for modeling different aspects of the system, the PRIMES model (E3MLab 2016) providing many key aspects of the energy system. The modeling framework takes into account global and EU market trends and the energy and climate policies already adopted by the EU and its Member States. The projections are based on a set of assumptions, including population growth, macroeconomic and oil price developments, technology improvements, and policies. Regarding policies, projections show the impacts of the full implementation of existing legally binding 2020 targets and EU legislation. As such, they also show the continued impact post 2020 of policies such as the EU Emissions Trading System Directive (including the Market Stability Reserve), the Energy Performance of Buildings Directive, Regulations on eco-design and on CO_2 emission standards for cars and vans, as well as the recently revised F-gas Regulation. Such policies notably influence current investment decisions, with impacts on the stock of buildings, equipment and cars, which have long-lasting effects post-2020 on GHG emissions or energy consumption (European Commission 2016a). The reference scenario is intended to be used as a benchmark for policy proposal assessment. Several targets are set against this reference scenario, which describes a business-as-usual development for economy, population growth, climate and transport outlook for the European Union.

The 2030 climate and energy framework (European Commission 2017b) sets three key targets for the year 2030:

- At least 40 % cut in greenhouse gas emissions (from 1990 level)
- At least 27 % share for renewable energy
- At least 27 % improvement in energy efficiency, as compared to a baseline projection acquired using the energy modeling framework.

The framework was adopted by EU leaders in October 2014. It builds on the 2020 climate and energy package, where the reference year is set to be 1990. A revised proposal for an energy efficiency target for 2030 (European Commission 2016b) has also been formulated. The proposal for a revised energy efficiency directive proposes that a more ambitious 30 % energy efficiency target is adopted. However, there are no binding targets for 2030 yet, but the Member States will set their national targets within the context of the proposal. The suggested 30 % energy efficiency target for the year 2030 would mean a cut of 23 % for primary energy consumption (TPES) and a cut of 17 % for final energy consumption (FEC) from the 2005 level in the EU as a whole (European Commission 2016b). The Member States can set their national contributions freely in this context. In absolute terms, calculated from the historical data used in the EU-28 LINDA model (based on IEA data), this would mean a final energy consumption of 923 Mtoe in the 28 European Union Member States, or a cut of about 190 Mtoe altogether.

This document describes the LINDA models constructed in the EUFORIE project. LINDA is an accounting framework model suitable for energy system analysis and scenario construction. The project team has constructed LINDA models for 24 individual European countries and one model for the European Union as a whole. The constructed LINDA models are available from the authors.

For some EU Member States, a lack of data or the statistical aggregation practice of the Member State in question has prevented the construction of a national LINDA model. Requirements for reliable data in a complex model such as the LINDA model are higher than simple availability of some kind of information on a specific topic. The data should be available in an aggregation level and level of detail roughly similar to the structure of the LINDA model. In some cases the available data can be transformed into an aggregation similar to LINDA aggregation with reasonable reliability. For most European Union Member States, data in more or less suitable format was available.

A national LINDA model is available for the following 21 European Union Member States:

- Austria
- Belgium
- Czech Republic
- Denmark
- Estonia
- Finland
- France
- Germany
- Greece
- Hungary
- Ireland
- Italy
- Luxembourg
- Netherlands
- Poland
- Portugal
- Slovakia
- Slovenia
- Spain

- Sweden
- United Kingdom.

In addition to this, LINDA models for the following non-EU countries are also available:

- Iceland
- Norway
- Switzerland.

The aggregated LINDA model (EU-28) can be used for analysis and scenario generation for the entire European Union (EU-28). This LINDA implementation is a useful model in generating projections and scenarios for the European Union in the context of energy policy planning and evaluation.

The LINDA models

General modeling approach

Any specific LINDA model implementation, such as a national model for an EU Member State, or an aggregated model for the EU as a whole, is a case or application of a more general LINDA model. The general LINDA model is an accounting framework, which takes detailed fuel and electricity use data by activity as input, as well as population and economic data, and can additionally take transportation-related input data used by an expansion module "TRANS-LINDA". The LINDA approach is used in the analysis of economy from an energy and emission perspective. The LINDA (Long-range Integrated Development Analysis) model is based on an intensity approach, building on the extended Kaya Identity (cf. Kaya 1990), which is used for identifying the drivers of CO_2 emissions. The following equation presents the main Kaya identity components used in the general LINDA model and approach:

$$CO2 = \frac{CO2}{TPES} \times \frac{TPES}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{POP} \times POP \qquad (1)$$

In Equation (1),

- CO_2 is carbon dioxide emissions from fuel combustion;
- TPES is total primary energy supply (including all fuels and other forms of primary energy, before the combustion process and transfer and distribution of electricity or heat);
- FEC is final energy consumption, meaning consumption of energy carriers such as district heat and electricity, and fuels used in residential heating and transport;
- GDP is gross domestic product in real prices; and
- POP is the amount of population.

This Kaya identity (Equation 1) forms the basic conceptual framework behind the LINDA model and the choice of modeled factors is somewhat based on the extended Kaya Identity[1]. Actual implemented LINDA models are so-called accounting framework-type of models, and compared against the extended Kaya Identity these models are much more detailed including different fuels and electricity, electricity production as well as different sectors of economy in the calculation procedures. Population growth is also accounted in the LINDA models, and an optional TRANS-LINDA module enables a more detailed look into transport sector activities, with a capacity to investigate changes in energy consumption and emissions resulting from the transition to biofuels and electrification of the vehicle fleet and transport activities.

[1] The extended Kaya identity and its simplified versions are used also in the ASA decomposition analysis applied in the EUFORIE project.

Implementation

LINDA models are implemented as single Microsoft Excel workbooks. This means that the use of any single model requires only the LINDA file implementing the model in question and Microsoft Excel (Version 15 / Microsoft Office 2013 version or higher recommended). The LINDA models also expand the capabilities of the spreadsheet application with VBA (Visual Basic for Applications) code for automation of several tasks and implementing model logic. Uses of VBA include some elements of the model's user interface, interpolation and extrapolation operations in case of missing data and certain other logic operations necessary for the proper functioning of the model. For this reason, the LINDA model user must allow execution of VBA code or "enable macros". Other than enabling the VBA code execution, in normal use of the LINDA models the user does not need to interact with the VBA code base or have any understanding of VBA.

Data sources

The LINDA model implementation files host the datasets they use within themselves, so no additional files are necessary. The data for the models has been acquired from several sources. Table 1 outlines the data sources for all LINDA implementations.

Table 1. Data sources of LINDA modeling.

Dataset	Data source
Fuel data	International Energy Agency (IEA), Extended Energy Balances (IEA 2016)
Economic data	World Bank, World Development Indicators: https://data.worldbank.org/data-catalog/world-development-indicators
Population data	United Nations Population Division, projections for population: https://esa.un.org/unpd/wpp/
Power plant data	European Union Directorate-General for Energy: http://ec.europa.eu/energy/en/data-analysis/country
TRANS-LINDA expansion module data	ODYSSEE database: http://www.indicators.odyssee-mure.eu/energy-efficiency-database.html

In addition to this, each implementation may have other data sources for data points or data series that have been missing in the main data sources. Other data sources may have been used in providing or imputing initial values for model parameters.

Features and suitability

LINDA models are intensity models, suitable for projecting use of various fuel types, electricity use, total energy use, price of electricity and resulting CO_2 emissions for the European Union Member States, for which the model has been implemented, or the EU-28 aggregate. The projections the model produces are based on user-defined assumptions of:

- changing fuel mixes in different sectors of the economy,

- change of activity in different economic sectors as annual sectoral GDP change rates,
- annual change in electricity and fuel use intensities per unit of generated GDP in different sectors,
- change in residential use of fuels and electricity
- population growth, and
- power plant investments.

LINDA models the energy production side at high level and the consumption side at a relatively low level, based on intensity trends. This approach is likely more practical than a low-level modeling of the consumption side, as the model aims to provide tools for modeling the characteristics of the energy system with a long outlook. Detailed, itemized modeling of consumption is very difficult for extensive time periods, and the intensity-based approach can be thought to be more realistic and practical.

The LINDA models have good fitness for investigating how different schedules for transitions in fuel use and electricity production play out in terms of emissions, how different investment plans for power plant capacity will cover the electricity needs in the system assuming different economic scenarios and how the electricity prices change, and how different scenarios for energy efficiency will influence the use of fuels and electricity and the need for new capacity, as well as reaching emission targets.

LINDA model structure

Sheets

The LINDA models consist of 36 visible MS Excel sheets that are available for the user and some hidden sheets used for implementing some of the model logic. The visible, user-accessible 36 sheets can be divided into - main interface sheet - output sheets - economic activity sector sheets - Total primary energy supply, emissions, electricity cost and electricity production details sheets - data collection sheets, used mainly for model logic - data sheets

Main interface sheet

The model user mainly interacts with the LINDA model through the main interface sheet ("Input") by laying out the high-level assumptions about economic expansion and changing electricity and fuel intensities. On this sheet, the user can determine

- the scenario start year,
- the time periods for the annual change rates (present in the input sheet) as their start and end years,
- annual change rates (in percentage) for GDP, electricity intensity and fuel intensity in agriculture and forestry, industry, transport and communication, and commercial sectors, electricity intensity in agriculture and forestry, industry, transport and communication, and commercial sectors,
- annual change rate for residential electricity use, and

- annual change rate for residential fuel use.

In the main interface sheet “Input”, there are also command buttons for printing all scenario figures on "Figures" sheet and protecting and unprotecting the model workbook. Printing of all scenario figures means that all figures created in the workbook will be copied to "Figures" sheet as new figures using a fixed figure width. The user is free to create all necessary figures from the model data and these figures will be copied at the print scenario figures command. The user is prompted which figure column in the "Figures" sheet should be used. Three columns are available. This functionality can be useful in comparison of outputs of the LINDA model under different scenarios.

Protecting the workbook means that the MS Excel workbook will be set to a state where changes are possible only to the data cells and input cells. See the next subsection for details on cell styling. If the workbook is protected, a command button for unprotecting the workbook will be present in the main interface sheet “input”. In the unprotected state, all cells of the workbook can be modified by the model user.

Output sheets

Sheets titled "Scenario" and "Figures" are the main output sheets of the model workbook. The "Scenario" sheet collects the most important projections of the model to the same sheet. The "Figures" sheet is used for printing all figures in the workbook in one of the available three figure columns, and this printing functionality can be summoned in the main interface sheet. There are also many model outputs and projections, that are not collected to the "Scenario" sheet. These outputs can be found in the economic activity sector sheets and emissions, electricity cost and electricity production details sheets. If needed, the model user can add the necessary outputs on the "Scenario" sheet after first unprotecting the model.

Economic activity sector sheets

The "Industry", "Transportation", "Commercial", "Residential", and "Agriculture and forestry" sheets model the energy-consuming economic activities. The parameters available for the model user to set on these sheets for the scenario building are the fuel use shares. In the "Transportation" sheet, user can also set several parameter values for the optional TRANS-LINDA module. These include the absolute fuel consumption values for fuels that are not used significantly in the transport sector, and the performance, energy intensity, and fuel use shares for both passenger transport and freight transport.

Total primary energy supply, emissions, electricity cost and electricity production details sheets

"TPES and CO_2" sheet models the total primary energy supply and emissions. The user may change the emission coefficients for different fuels on this sheet.

"ElectricityCost" sheet models the cost of electricity. The user may define the annual power plant investment costs, the annual operation and maintenance costs, and the annual fuel costs for different power plant types. The cumulative fuel costs and the total cumulative electricity production costs are computed based on this information and the information from other parts of the model.

"Electricity" sheet models the electricity production. The model user is able to create a scenario for future power plant investments. Is also possible to define efficiency factors for each power plant type, as a ratio of electricity output over fuel input, and their change over time. Load factors (the produced amounts of electricity over the potential production amounts) for all power plant types are also included, and the change in the load factors over time are defined on this sheet. The user can also set a percentage for taking the losses in electricity production and distribution into account.

Data collection sheets, used for model logic

The "ModelData" sheet pulls its contents from the "EstimatedData" sheet. It contains copies of the data series used in the LINDA model: computation sheets of the LINDA model refer to this sheet for getting data values. The user sets no parameters on the "ModelData" sheet but it can be utilized in creation of figures or producing tables about the historical data in the model.

The "EstimatedData" sheet is the data source for the "ModelData" sheet. This sheet pulls its data from the various data sheets of the model workbook. It also uses linear interpolation to fill in values for data points that are missing in the time series. Linear extrapolation is used to impute values for data points that are outside the time range of outside-sourced data in the data sheets. This functionality enables full computation of the LINDA models in cases where some data points might be missing and also starting the scenario projection from a few years ahead of the end of the provided outside-sourced data series.

The user can pull the data used by the model by clicking the "Estimate missing values for this sheet" command button on the "EstimatedData" sheet. This will flush the data on the "EstimatedData" sheet, pull the outside-sourced data from the data sheets and impute values for missing data points. After this, the user may change any values on the "EstimatedData" sheet as necessary.

The idea is that if values in the outside-sourced data are not credible or the user wishes to change some data points or series for some other reason, it can be done at this part of the model without tampering the original sourced data. Also if the estimation function imputes values that are not congruent with the assumptions of the scenario being created, or are otherwise unfit, those data points can be changed. The estimation function will clearly mark the data points pulled from sourced data sheets with the cell style "Data" and mark the data points estimated by the estimation function with the cell style "EstimatedData". See the next section "Cell styles and meanings" for more information about the use of cell styles in LINDA models. The "Flush data on this sheet" command button will flush all data on the sheet without performing the data pull or estimation.

Data sheets

The data sheets host the outside-sourced data used by the LINDA models. These sheets are "PowerplantData", "TransLindaData", "EconomyData", and all sheets whose name begins with "IEA", which host the data for fuels, sourced from the International Energy Agency. If data updates (new, up-to-date datasets from outside sources) are done, they should be done to these sheets. It is important to formulate the new data to the same format as the data sheets follow now.

Cell styles and meanings

The LINDA model workbooks use different cell styles for different types of information content. The model user inputs values mainly to "Input"-styled cells in the workbook. Addition or changes to data used by the model are done to "Data"-styled cells, which include "Data", "DataEstimated", "DataFromSimilarcountry" and "DataGuessed". These cell styles are the only ones that can be changed when the model is in protected state. The other cell styles visually convey information about the logic of the model and the contents of the cells they are used in. They are also used by the model for implementing some of the model logic. The important cell styles are tabulated below in Table 2.

Table 2. Important cell styles in the LINDA models.

Cell styling	**Meaning**
Blockheading	A heading of an interrelated block of data
Calc	A cell whose value is calculated on the basis of values of other model values
Copy	Cell that pulls its value from some other part of the model, used for convenience and clarity
Data	Cell that hosts outside-sourced data
DataEstimated	Data cell, where the value has been estimated by the estimation function
DataFromSimilarcountry	Data cell, where a missing value has been imputed based on available data from a similar country
DataGuessed	Data cell, where the missing value has been imputed with an educated guess (rare)
DataPlaceholder	Data cell, holding a value that is a placeholder for the actual data (rare)
Datasource	Information about the source for a block of data
Datasubheading	A subheading for a block of data
Expansion	Cells that are currently not used by LINDA model but where a model expansion might be implemented
InputCopy	Cell that pulls a user-defined value from some other part of the model, used for convenience and clarity
Instruction	Contains instructions for the user
Logic	Cell that is used in the model logic, normally not visible to the user
Meta	Contains metadata about a model component or data
Moduleheading	Heading for a model module
Notification	A cell style used for providing a notification for the user under some conditions
Seriesname	Name of a model data series
SumHeading	Heading for a summation row
Summation	Cells computing a summation of cells above them in the same data block
Year	Cells containing the year information for data points
Explanatory text	Contains explanatory information about a model component, data or input field
Input	Cells where user defines model parameter values
Note	Contains a note for consideration for model user
Output	Cells that compute some output of the LINDA model considered important

Usage of the LINDA models

Protecting and unprotecting the workbook

Each LINDA model implementation in an MS Excel workbook is supplied in protected mode. This means that only the contents of input cells and data cells can be changed. The parts of the model that perform computation are not open for editing in the protected mode. If these parts are to be changed, the workbook should be unprotected. In the unprotected mode, all parts of the workbook can be edited. The main interface sheet “input” features a command button for protecting/unprotecting the model workbook.

Updating and changing data

Annual data updates are needed in order to keep the model up to date and have the most recent information available. The LINDA models datasheets have a structure of data expected by the model, so the possible data updates should obviously follow the same data structure of the current data sheets.

Once the data on the data sheets has been updated, the new data is usable after pulling it to the model. by clicking "Estimate missing values for this sheet" button on the "EstimatedData" sheet. This will pull all the available data on the data sheets to the "EstimatedData" sheet, impute values for missing data points, and mark the pulled values with cell styling "Data" and the imputed values with cell styling "EstimatedData". The values on the "EstimatedData" sheet are the values that are actually used by the model, so it is important to pull the updated data values with the estimate missing values into the "EstimatedData" sheet after data updates have been made.

Changes to the values of data points or series are recommended to be made on the "EstimatedData" sheet after the data pull and estimation have been performed. This will keep the original outside-sourced data unchanged and the changed values can be more easily identified. This will also eliminate the need to change values of data points in various other parts of the model, as all parts pull the data they use ultimately from the "EstimatedData" sheet.

Taking LINDA models into use

The LINDA models constructed in the EUFORIE project include the bulk of the necessary data (Fuel use data for all fuels, economic data for the sectors, and population data). In addition to this, power plant data is required for creating energy scenarios. The historical power plant data is to be placed on the "PowerplantData" sheet. The aggregate EU-28 LINDA model includes the historical power plant data, as well as the national LINDA models for Austria, Denmark, Finland, Germany, Italy, and Spain. The other national LINDA models available do not include the power plant data.

User should also provide values for the different parameters used by the model, before creating scenarios from the model output. This means checking if the placeholder values for fuel mixes, annual changes of rates, emission coefficients, and other parameter values in the economic activity sector sheets and in the total primary energy supply, emissions, electricity cost and electricity production details sheets are congruent with the scenario being created. All values that the user should provide or check the placeholder values for suitability use the "Input" cell style.

Estimation of data

As noted, the LINDA models use a dataset derived from the supplied outside-sourced data, where the values for the missing data points have been estimated. For values missing within the time span of the provided data, linear interpolation is used. For values outside this time range, linear extrapolation based on available time series data from nearby years is used. The estimation is performed when the data pull functionality is used on the "EstimatedData" sheet by clicking the "Estimate missing values for this sheet" command button. After the data pull and estimation has been performed, the user may consider using some other estimation or imputation approach for any data point in the pulled and estimated data set. The values for data points used in the "EstimatedData" sheet are the ones that are used in the LINDA model computation.

Scenario start year

The start year of a scenario can be set in the main interface sheet “input”. The data estimation functionality of the LINDA model makes it possible to set the scenario start year to be later than the last year of available data: for the gap years, estimated values are used. The start year can be set within range of years 2005-2026. The most recent data in the models is from the year 2014 based on the data available in the International Energy Agency energy statistics and energy balances (IEA 2016).

Main sheet and main intensities

The main high-level parameters used in the scenario creation with the LINDA models are the annual sectoral GDP growth rates in different time periods of the created scenario, and annual sectoral fuel use and electricity use intensities for the different time periods of the created scenario. This way the outcomes of the created scenario can be tried out under various macro-level scenarios easily.

Other model parameters

The other model parameters reside in the economic activity sector sheets and the total primary energy supply, emissions, electricity cost and electricity production details sheets. Table 3 describes the LINDA model parameters that can be set in each sheet.

Table 3. LINDA model parameters.

Sheet	**Parameters**
Industry	Fuel mix in industrial sector; industry heat use
Transportation	Fuel mix in transport sector; absolute fuel consumption values for fuels, performance, energy intensity, and fuel use shares for passenger and freight transport (TRANS-LINDA expansion module
Commercial	Fuel mix in the commercial sector
Residential	Fuel mix in the residential sector; residential heat use
Agriculture and forestry	Fuel mix in the agriculture and forestry sector
TPES and CO_2	Fuel emission coefficients
ElectricityCost	Power plant investment costs; plant maintenance and operation costs; fuel costs;
Electricity	New power plants; efficiency of electricity production for different power plant types; capacity/load factors for power plant types; losses

LINDA scenarios for the EU-28 aggregate

The baseline and energy efficiency scenarios presented in this document are both derived from the same LINDA model template for aggregated EU-28 Member States. The baseline scenario uses energy intensity trends derived from a structural decomposition analysis of the EU-28 economy: the structural decomposition isolates the energy efficiency improvement from the change in the economic activity level and the structural shift towards differently energy-intensive activities in the total economy. The scenario for the future net electricity generation capacity is based on the EU Reference Scenario 2016, based on the outputs of the PRIMES and GAINS models (European Commission 2016a). In the energy efficiency scenario, the net electricity generation capacity is changed to meet the desired targets. The scenario details are fully described in the descriptions in the following.

The LINDA approach in comparison to the EU Reference Scenario 2016 modeling framework approach

The modeling framework based on the PRIMES modeling suite as the core element. PRIMES is a partial equilibrium model providing medium to long term projections, and a combination of behavioral modelling following a micro-economic foundation with engineering and system aspects is mentioned as a distinctive feature of PRIMES (E3MLab 2016). The equilibrium approach in modeling relies on macroeconomic and microeconomic assumptions that do not necessarily correspond to what is most significant in the system. It uses optimization and probabilistic methods, which result in growing inaccuracies in the longer term. While this kind of modeling approach can be useful in providing projections, it can be argued that an accounting framework approach employed by LINDA model can be more suitable for strategic policy-making in the context of uncertainty. The equilibrium approach might make investigating real policy decisions and transition management difficult, as the system model embeds current real-world system dynamics, limiting the scope of the considered policy. LINDA model has the advantage of having a great deal of transparency and flexibility in terms of testing different assumptions, as well as ease of use.

Energy efficiency trends

Decomposition analysis is used to divide the change of an explained variable to several factors that jointly contribute to its change. The change in the energy use in a sector of an economy can be caused by general growth of economic activity in the whole economy, shifts in the shares of activity between the economic sectors and changes in the energy intensity. Structural decomposition analysis was used here to investigate the energy intensity trends of EU-28 economy. The aim was to clearly show the effect of energy efficiency changes in the different sectors on the total energy use, by quantifying the effects of increased general economic activity and the shift of activity between the sectors with different energy intensity, and isolating them from the impacts of changing energy efficiency.

The decomposition technique used for the decomposition analyses in this report is based on the Sun-Shapley method (cf. Ang 2004). This technique is used to divide the change in FEC to three components: the activity (or quantity) effect, the structural effect and the intensity effect:

- The activity/quantity effect is the measure of the change of volume of activity that drives the energy use. In this analysis, it is measured as sectoral value added.
- The structural effect represents the impact of change of shift of activity between the different sectors. This is measured by the share of value added in the different sectors.
- The intensity effect is the measure of the impact of energy efficiency, measured as unit of energy over unit of value, i.e. FEC/GDP.

The decomposition technique used here divides the change in the explained variable so that the sum of all effects in all sectors is equal to the total change in the explained variable, and also so that the sum of all effects in a single sector sum to be the change in the energy consumption in the sector in question.

To isolate the energy efficiency change, to be used as the energy intensity change in the LINDA model, a structural decomposition analysis of FEC for EU-28 has been carried out by using GDP in constant prices as the quantity variable. The time period is 2002-2014, using an average of values from 2002 to 2004 as the value for base year 2002 and an average of values from 2013 and 2014 as the value for 2014. This decomposition yields an intensity effect for the time period, and the annual percentual intensity effect can be computed from it. These annual percentual efficiency improvements are then fed into the LINDA model as the trend-based baseline electricity and fuel use intensity improvement. The decomposition analysis results are tabulated in Table 4.

Table 4. Structural decomposition analysis results and annual energy efficiency change in the EU-28 as a whole, represented by the intensity (I) effect. Negative values for the intensity effect reflect the effect of the energy efficiency improvement on energy use.

	Q	I	S	Annual intensity change
Agriculture, forestry, fishing	0.33 %	-0.51 %	-0.24 %	-0.04 %
Industry (mining, construction, utilities)	3.50 %	-6.67 %	-3.38 %	-0.53 %
Transport, storage and communication	3.87 %	-9.84 %	4.24 %	-0.79 %
Services	1.74 %	-1.06 %	0.40 %	-0.08 %

Figure 1 presents decomposition results of annual intensity effect in the different economic sectors in the EU-28 aggregate. In this case, an incremental decomposition has been carried out by comparing each year to the previous year. There is a lot of fluctuation in the annual intensity effects (Figure 1), so the average annual value (Table 4) has been used as input in the LINDA modeling for a good reason.

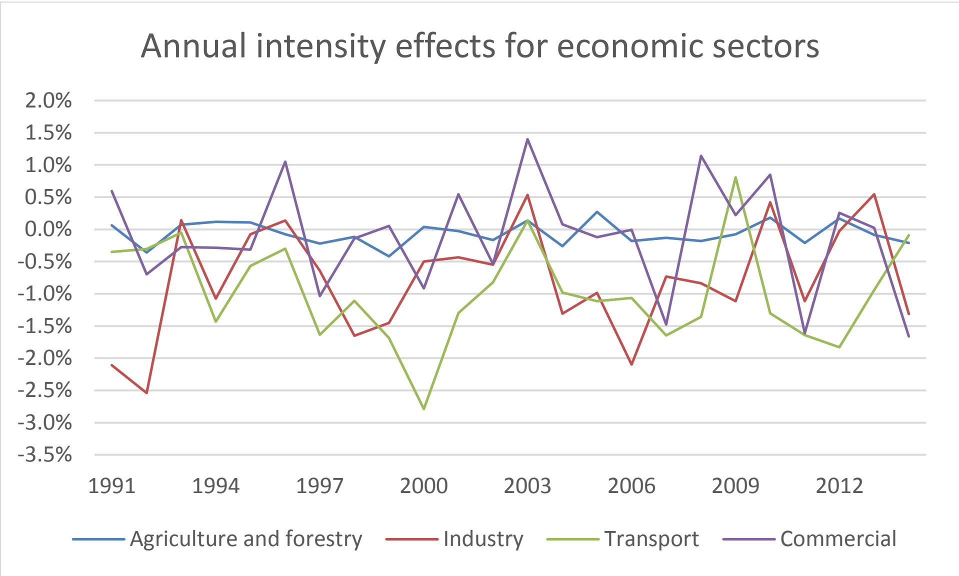

Figure 1. Decomposed annual intensity effects for different economic sectors in the EU-28 aggregate.

LINDA EU-28 baseline scenario

The presented energy efficiency baseline scenario is, for most of the LINDA model inputs, based on the EU Reference Scenario 2016. The LINDA model follows the reference scenario in the economic and energy sector development: the growth rates of value added in different economic sectors and the development of the electricity generation capacity and power plant investments are very similar to the reference scenario. As the structure and logic of the LINDA model differs from the PRIMES-GAINS modeling framework, complete similarity in scenarios is an impossibility (and in some way counter-productive if the purpose is to have an alternative modeling approach). In terms of energy efficiency improvements (represented in LINDA as the annual energy intensity changes in different sectors of the economy), the energy efficiency baseline scenario is based on extrapolation of the current trend of energy efficiency improvement.

The annual changes in GDP shares per sector are presented in Table 5. The EU Reference Scenario projects quite modest average economic growth. This is a conservative assumption from the perspective of doing energy efficiency related modeling: a fast economic growth, especially in non-energy-intensive commercial sector would obviously result in the energy intensity of the economy to decrease fast.

Table 5. Assumed average annual changes in sectoral value added (GDP) in the LINDA EU-28 baseline scenario.

Annual percentual changes, GDP	2009-2014	2015-2019	2020-2024	2025-2029	2030-2034	2035-2040	2041-2053
Agriculture and forestry	0.06 %	0.30 %	0.25 %	0.25 %	0.28 %	0.29 %	0.30 %
Industry	1.08 %	0.70 %	0.59 %	0.59 %	0.65 %	0.67 %	0.70 %
Transportation, communication	1.91 %	1.30 %	1.09 %	1.09 %	1.20 %	1.25 %	1.20 %
Commercial	1.03 %	2.05 %	1.72 %	1.70 %	1.85 %	1.91 %	1.75 %
Total	1.12 %	1.62 %	1.38 %	1.37 %	1.51 %	1.57 %	1.49 %

Energy use and value added are decoupling in the long run, and the industrial and transport sector are especially significant in terms of this development. Tables 6 and 7 present the sectoral electricity intensity and the annual changes in the sectoral fuel intensity, respectively. The development for both intensities is equal in the baseline scenario. The initial intensity change rate (for years 2015-2019) in the baseline scenario is based on historical average intensity change during the period 2002-2014. The annual rates are based on the decomposition of the intensity effect for FEC, reported in Table 4 (see above).

Table 6. Assumed average annual changes in sectoral electricity intensity and annual residential electricity use change in the LINDA EU-28 baseline scenario.

Electricity intensity change	**2009-2014**	**2015-2019**	**2020-2024**	**2025-2029**	**2030-2034**	**2035-2040**	**2041-2053**
Agriculture and forestry, electricity intensity	-0.04 %	-0.04 %	-0.05 %	-0.06 %	-0.07 %	-0.08 %	-0.10 %
Industry, electricity intensity	0.00 %	-0.53 %	-0.64 %	-0.76 %	-0.92 %	-1.10 %	-1.32 %
Transportation and communication, electricity intensity	-1.97 %	-0.79 %	-0.95 %	-1.14 %	-1.37 %	-1.64 %	-1.97 %
Commercial, electricity intensity	-1.24 %	-0.08 %	-0.10 %	-0.12 %	-0.14 %	-0.17 %	-0.20 %
Residential, electricity use change	-0.85 %	2.00 %	2.00 %	1.00 %	1.00 %	0.50 %	0.00 %

The residential electricity consumption is assumed to grow 2 % annually in the period 2015-2024, then by 1 % annually in the period 2025-2034, 0.5 % annually between 2035-2040 and remain at the same level for period 2041 onwards (Table 6). The fuel use in the residential sector is assumed to decline by one per cent annually for the entire scenario period (Table 7).

Table 7. Assumed average annual changes in sectoral fuel use intensity and annual residential fuel use change in the LINDA EU-28 baseline scenario.

Energy (fuel use) intensity change	**2009-2014**	**2015-2019**	**2020-2024**	**2025-2029**	**2030-2034**	**2035-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	-1.09 %	-0.04 %	-0.05 %	-0.06 %	-0.07 %	-0.08 %	-0.10 %
Industry, fuel intensity	-1.13 %	-0.53 %	-0.64 %	-0.76 %	-0.92 %	-1.10 %	-1.32 %
Transportation and communication, fuel intensity	-2.77 %	-0.79 %	-0.95 %	-1.14 %	-1.37 %	-1.64 %	-1.97 %
Commercial, fuel intensity	-3.16 %	-0.08 %	-0.10 %	-0.12 %	-0.14 %	-0.17 %	-0.20 %
Residential, fuel use change	-3.31 %	-1.00 %	-1.00 %	-1.00 %	-1.00 %	-1.00 %	-1.00 %

On the basis of the assumptions made above in Table 5, Table 6 and Table 7, a set of essential characteristics of the energy system in the LINDA EU-28 baseline scenario will be presented in the following. The GDP per sector will develop as presented in Figure 2, as a result from the assumptions made in Table 6 above. Economic growth in the commercial sector is significantly faster than in the other sectors, so the share of the commercial sector in the entire EU-28 economy increases.

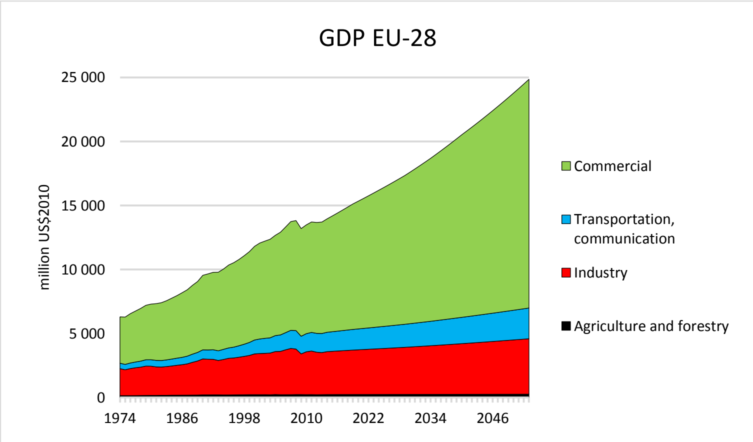

Figure 2. GDP per economic sector (million US$ in 2010 prices) in the LINDA EU-28 baseline scenario.

The final energy consumption (fuels and electricity) of the major economic sectors in the LINDA EU-28 baseline scenario is presented in Figure 3. The share of the commercial sector in energy consumption is increasing, and by the end of the scenario period, the shares of all sectors except agriculture and forestry are roughly similar. However, energy consumption in the commercial sector increases at a slower rate than its activity in economic terms (growth of its share of GDP).

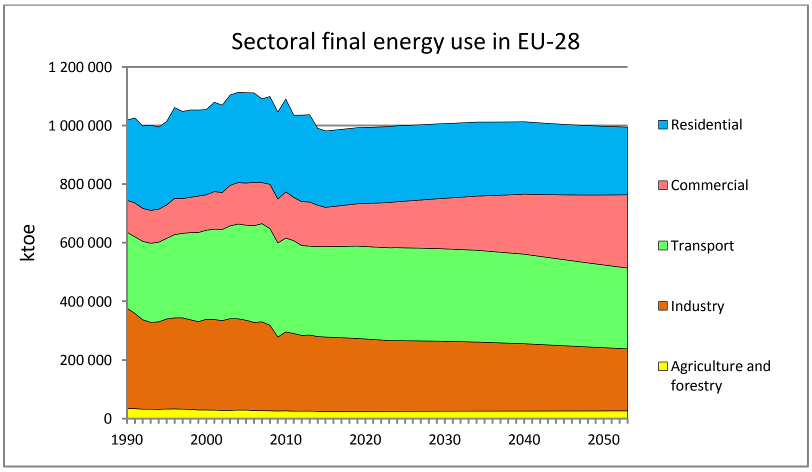

Figure 3. Final energy use per sector in the LINDA EU-28 baseline scenario.

Electricity consumption in the LINDA EU-28 baseline scenario increases especially in the commercial and residential sectors (Figure 4).

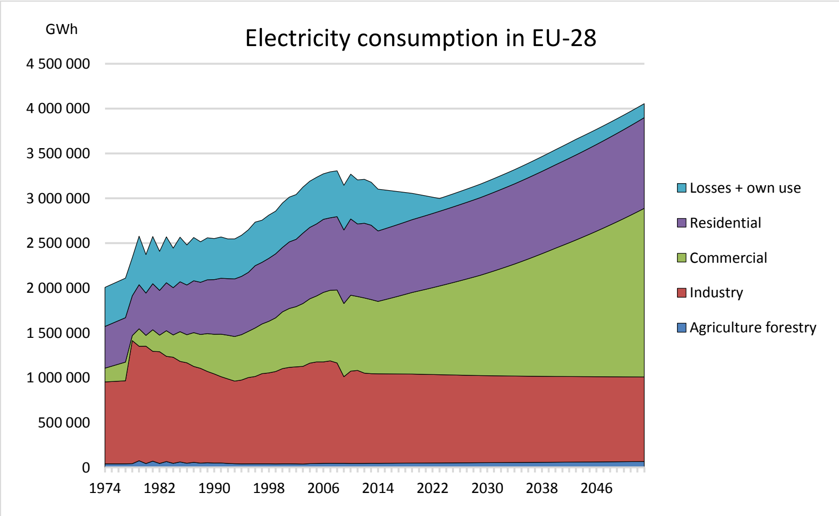

Figure 4. Electricity consumption by sector in the LINDA EU-28 baseline scenario.

The EU 2030 climate and energy framework (European Commission 2017) sets a target for 2030 regarding the share of renewable energy, namely 27 % of the primary energy mix. Table 9 presents the share of different energy sources in the energy mix of the LINDA EU-28 baseline scenario. The power plant investment assumption (Figure 4), derived from the EU Reference Scenario 2016 and imported into LINDA EU-28 baseline scenario, results a 23 % share for renewable energies in the 2030 primary energy mix (Table 8), which falls significantly short of the 27 % target. Increase in the power plant capacity rests heavily on renewable energies (wind, solar and biofuels), but to some content also on natural gas (Figure 5).

Table 8. Share of different energy sources in the EU-28 energy mix in the LINDA EU-28 baseline scenario.

TPES shares	1990	2005	2015	2020	2030	2050
Coal	27.6 %	17.9 %	16.0 %	12.3 %	6.9 %	2.4 %
Peat	0.2 %	0.2 %	0.0 %	0.0 %	0.1 %	0.0 %
Crude oil	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
LPG	1.2 %	1.3 %	1.7 %	1.4 %	1.0 %	0.9 %
Motor gasoline	9.8 %	7.5 %	5.8 %	5.6 %	4.9 %	2.9 %
Diesel	15.0 %	17.9 %	18.3 %	17.5 %	17.2 %	12.2 %
Fuel oil	6.5 %	2.7 %	0.4 %	0.5 %	0.6 %	0.4 %
Other oil products	1.3 %	2.2 %	0.9 %	1.2 %	1.2 %	0.9 %
Natural gas	18.2 %	25.5 %	24.7 %	31.3 %	28.5 %	27.1 %
Nuclear	14.9 %	16.8 %	17.0 %	17.3 %	16.6 %	15.3 %
Hydro	1.8 %	1.7 %	2.4 %	2.3 %	2.5 %	3.0 %
Geothermal	0.2 %	0.3 %	0.0 %	0.0 %	0.0 %	0.0 %
Solar	0.0 %	0.0 %	0.6 %	0.7 %	1.2 %	2.1 %
Wind	0.0 %	0.4 %	1.7 %	2.1 %	3.8 %	7.4 %
Biofuels and waste	3.1 %	5.5 %	10.4 %	7.8 %	15.5 %	25.5 %
Hydrogen	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Share of renewables in energy mix	5.1 %	8.0 %	15.0 %	13.0 %	23.1 %	38.0 %
Total Fuel use sum	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %

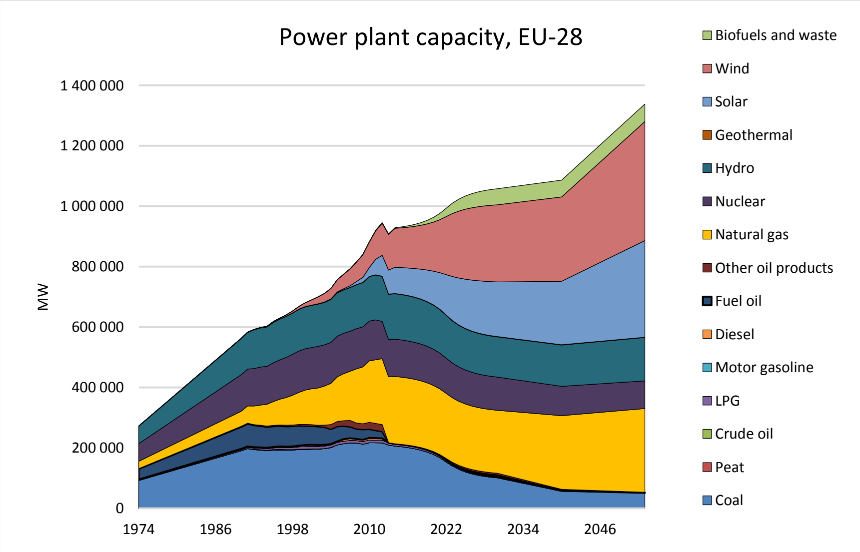

Figure 5. Development of power plant capacity by primary energy source in the LINDA EU-28 scenarios.

Regarding CO_2 emissions from fuel combustion, the LINDA EU-28 baseline scenario assumptions lead to a development presented in Table 10. By the end of the scenario period, 80 % of the CO_2 emissions are caused by two fossil fuels, natural gas and diesel (Figure 6).

The LINDA EU-28 baseline projection gives slightly lower figures for CO_2 emissions than the EU reference scenario 2016 (Table 9). The 40 % cut in CO_2 emissions by 2030 stipulated in the EU 2030 climate and energy framework (European Commission 2017b) will not be reached in either of the scenarios. The LINDA EU-28 energy efficiency scenarios (to be presented in the next chapter) will examine assumptions that would make it possible to reach the 40 % decrease in CO_2 emissions and the suggested targets on energy efficiency by the year 2030.

Table 9. CO_2 emissions in the LINDA EU-28 baseline scenario in comparison to the EU Reference Scenario 2016 (cf. European Commission 2016a).

CO2 emissions	**2020**	**2030**	**2050**
CO2 Mtons (EUROLINDA)	2900	2324	1575
CO2 (compared to 1990, EUROLINDA)	-20.0 %	-35.9 %	-56.6 %
CO2 (compared to 1990, EU reference scenario)	-26 %	-35 %	-48 %

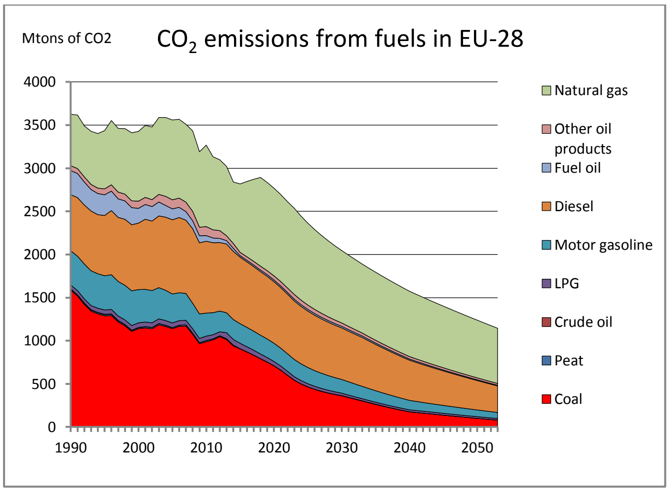

Figure 6. CO_2 emissions from fuel combustion in the LINDA EU-28 baseline scenario.

The proposed EU-28 energy efficiency target of a 27 % reduction by 2030 from the value of the reference scenario in the same year (interpreted as a 23 % reduction in primary energy use and a 17 % reduction in final energy use from the 2005 level), is not reached in the LINDA EU-28 baseline scenario. In this scenario, the reduction of FEC is 12.1 % and reduction in TPES 9.5 % (Table 10). Reaching the proposed energy efficiency target would require additional improvements to the trends of primary and final energy consumption. Assumptions for a set of LINDA EU-28 energy efficiency scenarios and related energy and CO_2 projections will be dealt with in the next chapter.

Table 10. Development of gross domestic product (GDP), total primary energy use (TPES), final energy consumption (FEC), and energy intensities (TPES/GDP, FEC/GDP and TPES/FEC) in the LINDA EU-28 baseline scenario.

	1990	2005	2015	2020	2030	2050
GDP (const. 2010 Billion US$)	9544	12911	14178	15329	17595	23771
FEC (ktoe)	1018254	1112141	981472	993323	1006547	997338
TPES (ktoe)	1398847	1547751	1411153	1418492	1361184	1265389
TPES/GDP	146,6	119,9	99,5	92,5	77,4	53,2
FEC/GDP	106,7	86,1	69,2	64,8	57,2	42,0
TPES/FEC	1,37	1,39	1,44	1,43	1,35	1,27
FEC change from 2005	-9,6 %	0,0 %	-8,8 %	-8,4 %	-12,1 %	-18,2 %
TPES change from 2005	-8,4 %	0,0 %	-11,7 %	-10,7 %	-9,5 %	-10,3 %
TPES/GDP change from 2005	22,3 %	0,0 %	-17,0 %	-22,8 %	-35,5 %	-55,6 %
FEC/GDP change from 2005	23,9 %	0,0 %	-19,6 %	-24,8 %	-33,6 %	-51,3 %
TPES/FEC change from 2005	-1,3 %	0,0 %	3,3 %	2,6 %	-2,8 %	-8,8 %

LINDA EU-28 energy efficiency scenarios

In the following, assumptions of the LINDA EU-28 baseline scenarios will be changed in order to meet the energy efficiency target and other energy policy targets set for the EU as a whole. The LINDA EU-28 energy efficiency scenarios EFF1-EFF4 are constructed in the following. These scenarios examine the conditions, where a development in line with the targets set for energy efficiency, CO_2 emissions, and the share of renewable energies in the energy mix, would be possible.

In the first energy efficiency scenario, LINDA EU-28 EFF1, a continuation of the average annual change rate of electricity and fuel intensities during the period 2009-2014 is assumed (Table 11). During that period, especially fuel intensity decreased significantly in all economic sectors. Electricity intensity decreased in all other sectors than industry. All other assumptions are similar to the ELINDA EU-28 baseline scenario.

Table 11. Assumed electricity and fuel intensity changes in the LINDA EU-28 EFF1 scenario.

Electricity intensity ktoe/million USD	2009-2014	2015-2019	2020-2024	2025-2029	2030-2034	2035-2040	2041-2053
Agriculture and forestry, electricity intensity	-0,04 %	-0,04 %	-0,04 %	-0,04 %	-0,04 %	-0,04 %	-0,04 %
Industry, electricity intensity	0,00 %	0,00 %	0,00 %	0,00 %	0,00 %	0,00 %	0,00 %
Transportation and communication, electricity intensity	-1,97 %	-1,97 %	-1,97 %	-1,97 %	-1,97 %	-1,97 %	-1,97 %
Commercial, electricity intensity	-1,24 %	-1,24 %	-1,24 %	-1,24 %	-1,24 %	-1,24 %	-1,24 %
Residential electricity use (not intensity)	-0,85 %	-0,85 %	-0,85 %	-0,85 %	-0,85 %	-0,85 %	-0,85 %
Energy (fuel use) intensity change	**2009-2014**	**2015-2019**	**2020-2024**	**2025-2029**	**2030-2034**	**2035-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	-1.09 %	-1.09 %	-1.09 %	-1.09 %	-1.09 %	-1.09 %	-1.09 %
Industry, fuel intensity	-1.13 %	-1.13 %	-1.13 %	-1.13 %	-1.13 %	-1.13 %	-1.13 %
Transportation and communication, fuel intensity	-2.77 %	-2.77 %	-2.77 %	-2.77 %	-2.77 %	-2.77 %	-2.77 %
Commercial, fuel intensity	-3.16 %	-3.16 %	-3.16 %	-3.16 %	-3.16 %	-3.16 %	-3.16 %
Residential, fuel use change	-3.31 %	-3.31 %	-3.31 %	-3.31 %	-3.31 %	-3.31 %	-3.31 %

The assumptions of the LINDA EU-28 EFF1 scenario are favourable from the perspective of the energy-related EU targets. Table 12 shows that the energy efficiency targets, operationalised as a 17 % decrease in final energy consumption (FEC) and 23 % decreased in primary energy consumption (TPES) from the 2005 level, would be met. Even the suggested CO_2 target (40 % by the year 2030 from the 1990 level) would be met, but the share of renewables in the energy mix would be 23.6 % in 2030 and remain below the 27 % target.

Table 12. Energy use and CO_2 emission reductions in the LINDA EU-28 EFF1 scenario.

	2030	Target
FEC compared to 2005	-28.0 %	-17 %
TPES compared to 2005	-25.5 %	-23 %
CO2 reduction (compared to 1990)	-46.7 %	-40 %

In the LINDA EU-28 EFF2 scenario, continuation of a longer historical trend (average annual changes during the years 2000-2014) in electricity and fuel intensities is assumed (Table 13). Other assumptions are similar to the EFF1 and baseline scenarios. With these assumptions, the CO_2 reduction target for the year 2030 would also be met, but the energy efficiency target (operationalized as a 17 % cut in final energy (FEC) consumption and 23 % cut in primary energy (TPES) consumption, would be met only for final energy consumption (Table 14). The reduction of TPES in the LINDA EU-28 EFF2 scenario by the year 2030 from the 2005 level (20.3 %) remains smaller than the target (23 %).

Table 13. Assumed electricity and fuel intensity changes in the LINDA EU-28 EFF2 scenario.

Electricity intensity change	2000-2014	2015-2019	2020-2024	2025-2029	2030-2034	2035-2040	2041-2053
Agriculture and forestry, electricity intensity	0.63 %	0.63 %	0.63 %	0.63 %	0.63 %	0.63 %	0.63 %
Industry, electricity intensity	-0.80 %	-0.80 %	-0.80 %	-0.80 %	-0.80 %	-0.80 %	-0.80 %
Transportation and communication, electricity intensity	-3.40 %	-3.40 %	-3.40 %	-3.40 %	-3.40 %	-3.40 %	-3.40 %
Commercial, electricity intensity	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %	0.37 %
Residential, electricity use change	0.65 %	0.65 %	0.65 %	0.65 %	0.65 %	0.65 %	0.65 %
Energy (fuel use) intensity change	**2000-2014**	**2015-2019**	**2020-2024**	**2025-2029**	**2030-2034**	**2035-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	-1.90 %	-1.90 %	-1.90 %	-1.90 %	-1.90 %	-1.90 %	-1.90 %
Industry, fuel intensity	-2.45 %	-2.45 %	-2.45 %	-2.45 %	-2.45 %	-2.45 %	-2.45 %
Transportation and communication, fuel intensity	-2.24 %	-2.24 %	-2.24 %	-2.24 %	-2.24 %	-2.24 %	-2.24 %
Commercial, fuel intensity	-1.10 %	-1.10 %	-1.10 %	-1.10 %	-1.10 %	-1.10 %	-1.10 %
Residential, fuel use change	-1.20 %	-1.20 %	-1.20 %	-1.20 %	-1.20 %	-1.20 %	-1.20 %

Table 14. Energy use and CO_2 emission reductions in the year 2030 in the LINDA EU-28 EFF2 scenario.

	2030	Target
FEC compared to 2005	-20.9 %	-17 %
TPES compared to 2005	-20.3 %	-23 %
CO2 reduction (compared to 1990)	-44.0 %	-40 %
Share of renewables in energy mix	23.8 %	27 %

In the LINDA EU-28 EFF3 scenario, the assumptions of economic growth have been changed. The absolute growth rate is the same as in the EU Reference Scenario 2016 and all previous LINDA EU-28 scenarios (baseline, EFF1 and EFF2), but growth in the commercial sector is faster and in other sectors slower (Table 15). Table 16 shows that the outcome would be quite similar to the EFF2 scenario, i.e. the 2030 CO_2 and FEC targets would be met, but the decrease in TPES (20.9 % from the 2005 level) would remain slightly smaller than the target (23 %).

Table 15. Assumed average annual changes in sectoral value added in the LINDA EU-28 EFF3 scenario.

Annual percentual changes, GDP	2000-2014	2015-2019	2020-2024	2025-2029
Agriculture and forestry	0.33 %	0.30 %	0.25 %	0.25 %
Industry	0.36 %	0.00 %	0.00 %	0.00 %
Transportation, communication	2.39 %	1.50 %	1.32 %	1.09 %
Commercial	1.37 %	2.25 %	1.88 %	1.85 %
Total	1.20 %	1.62 %	1.39 %	1.38 %

Table 16. Energy use and CO_2 emission reductions in the year 2030 in the LINDA EU-28 EFF3 scenario.

	2030	Target
FEC compared to 2005	-21.7 %	-17 %
TPES compared to 2005	-20.9 %	-23 %
CO2 reduction (compared to 1990)	-44.1 %	-40 %
Share of renewables in energy mix	23.8 %	27 %

On the other hand, assuming most of the economic growth in the energy-intensive industrial sector (Table 17), with similar electricity and fuel use intensity development to scenario EFF3 in Table 13 above, the CO_2 emission reduction target would be met (Table 18). Under the assumptions presented in Table 13 and 17, the reduction in FEC would be just 16 % from the 2005 level, falling short of the 17

% target (Table 18). The reduction in TPES, 16.7 % from the 2005 level, would fall significantly short of the targeted 23 % (Table 18).

Table 17. Assumed annual changes (%) in sectoral value added (GDP) in the LINDA EU-28 EFF4 scenario.

Annual percentual changes, GDP	2000-2014	2015-2019	2020-2024	2025-2029
Agriculture and forestry	0.33 %	0.30 %	0.25 %	0.25 %
Industry	0.36 %	3.50 %	2.50 %	2.30 %
Transportation, communication	2.39 %	1.25 %	1.00 %	1.00 %
Commercial	1.37 %	1.00 %	1.00 %	1.00 %
Total	1.20 %	1.64 %	1.39 %	1.36 %

Table 18. Energy use and CO_2 emission reductions in the year 2030 in the LINDA EU-28 EFF4 scenario.

	2030	Target
FEC compared to 2005	-16.0 %	-17 %
TPES compared to 2005	-16.7 %	-23 %
CO2 reduction (compared to 1990)	-42.2 %	-40 %
Share of renewables in energy mix	24.0 %	27 %

As a general conclusion, reaching a fixed target in energy use, either in terms of primary energy or final energy consumption, depends very much on how different economic sectors generate the increase in economic activity. It appears that if growth in the (energy intensive) industrial sector is fast, fixed targets on energy use become difficult to reach. However, reaching the target may seem more feasible also by assuming e.g. a different profile of investments to new power plant capacity, or different development of the capacity factors of power plants using different primary energy sources. In all LINDA EU-28 scenarios presented here the power plant capacity (presented in Figure 5 above) and the capacity factors are similar. Increase of capacity focuses mostly on wind, solar and natural gas.

Tanle 19 summarizes the findings from the LINDA EU-28 scenarios in relation to the suggested EU energy policy targets in 2030 regarding final energy consumption (FEC), total primary energy supply (TPES), carbon dioxide emissions from fuel combustion (CO_2) and the share of renewable sources in the primary energy mix.

Table 19. Summary of the LINDA EU-28 scenarios in terms of suggested EU 2030 energy policy targets.

Indicator	EU target 2030	LINDA EU-28 scenario				
		Baseline 2030	EFF1 2030 higher efficiency	EFF2 2030 lower efficiency	EFF3 2030 (EFF2 + commercial growth)	EFF4 2030 (EFF2 + industrial growth)
FEC	-17 % from 2005	-12.1 %	-28.0 %	-20.9 %	-21.7 %	-16.0 %
TPES	-23 % from 2005	-9.5 %	-25.5 %	-20,3 %	-20.9 %	-16.7 %
CO2	-40 % from 1990	-35.9 %	-46.7 %	-44.0 %	-44.1 %	-42.2 %
Renewables	share 27 %	23.1 %	23.6 %	23.8 %	23.8 %	24.0 %

LINDA scenarios for the selected EU Member States

As stated in the introduction, LINDA models have been constructed for all the EU Member States with sufficient data availability. Regarding the data availability, information about the power plant capacity for generating energy carriers such as electricity and heat in the coming years seems to be a bottleneck – in many Member States, new capacity is under construction and planned, but not included in the Eurostat or other statistics yet. For this reason, information about power plant capacity was included in a few national LINDA models only, the models for the Member States where the EUFORIE partners come from were preferred. In the following, a baseline scenario (BAU) and two different alternative scenarios, an energy efficiency scenario (EFF) and an industrial scenario (IND), will be presented for four EU Member States: Finland, Germany, Italy, and Spain.

Finland

Scenario "LINDA Finland BAU" (Table 20) is a baseline scenario, where past trends of economic development and electricity intensity continue. The fuel intensity changes are assumed to be similar to the BAU scenario in all other scenarios. Tables 20-22 show the assumptions for economic development and the assumed changes in electricity and fuel efficiencies for the LINDA scenarios for Finland.

Scenario "LINDA Finland EFF" (Table 21) is an energy efficiency scenario, which has similar economic growth figures for all sectors (agriculture and forestry, industry, transportation and communication, and commercial) to the BAU scenario. In the EFF scenario, electricity efficiency in the industrial and commercial sectors is assumed to improve faster than in the BAU scenario. In transport and communications sector, electricity intensity of the EFF scenario is the same as in the BAU scenario. In this sector, electricity intensity is assumed to increase in the future with a shift to more electrical vehicles.

Scenario "LINDA Finland IND" (Table 22) is an industrial scenario with higher growth figures for industrial sector and lower growth rate for commercial sector than in the BAU and EFF scenarios. This means that the IND scenario assumes a structural change taking place in the economy, towards more industrial development. The electricity intensity figures in the IND scenario are similar to the BAU scenario, so this scenario is analyzing the impact of structural change in the economy, and the possible restrictions caused by it.

Table 20. Assumptions of the LINDA Finland BAU scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Finland BAU			Scenario start year	2015	(2005-2026)		
Start years of periods	1974	1991	2001	2009	2015	2017	2021	2026	2031	2041
End years of periods	1990	2000	2008	2014	2016	2020	2025	2030	2040	2053
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
GDP	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry	0.9 %	0.4 %	1.0 %	-1.2 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Industry	2.6 %	4.7 %	4.2 %	-1.9 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Transportation, communication	3.4 %	5.0 %	2.8 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.5 %	1.9 %	2.0 %	0.5 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Total	3.1 %	3.0 %	2.8 %	-0.1 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Electricity intensity ktoe/million USD	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, electricity intensity	5.2 %	-1.3 %	9.1 %	-1.1 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %
Industry, electricity intensity	1.1 %	-1.1 %	-3.8 %	3.0 %	-1.0 %	-1.5 %	-1.5 %	-1.5 %	-1.5 %	-1.5 %
Transportation and communication, electricity intensity	8.4 %	-2.5 %	0.9 %	-2.0 %	-0.5 %	0.0 %	0.0 %	0.0 %	1.0 %	1.0 %
Commercial, electricity intensity	3.4 %	0.4 %	0.3 %	-0.3 %	0.0 %	-1.0 %	-1.5 %	-1.5 %	-1.5 %	-1.5 %
Residential electricity use (not intensity)	6.7 %	1.7 %	0.7 %	0.0 %	2.0 %	2.0 %	1.0 %	1.0 %	0.5 %	0.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Energy (fuel use) intensity changes ktoe/mill.	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	2.5 %	-2.0 %	-1.5 %	0.3 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-0.9 %	-2.8 %	-4.8 %	5.3 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %
Transportation and communication, fuel intensity	-0.1 %	-4.5 %	-1.8 %	-2.1 %	-1.0 %	-2.0 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %
Commercial, fuel intensity	n.a.	n.a.	-5.5 %	-1.3 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %
Residential use (not intensity)	0.7 %	-6.4 %	-0.5 %	-2.5 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

Table 21. Assumptions of the LINDA Finland EFF scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Finland EFF			Scenario start year	2015	(2005-2026)		
Start years of periods	1974	1991	2001	2009	2015	2017	2021	2026	2031	2041
End years of periods	1990	2000	2008	2014	2016	2020	2025	2030	2040	2053
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
GDP	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry	0.9 %	0.4 %	1.0 %	-1.2 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Industry	2.6 %	4.7 %	4.2 %	-1.9 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Transportation, communication	3.4 %	5.0 %	2.8 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.5 %	1.9 %	2.0 %	0.5 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Total	3.1 %	3.0 %	2.8 %	-0.1 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Electricity intensity ktoe/million USD	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, electricity intensity	5.2 %	-1.3 %	9.1 %	-1.1 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %
Industry, electricity intensity	1.1 %	-1.1 %	-3.8 %	3.0 %	-1.0 %	-1.8 %	-2.0 %	-2.1 %	-2.2 %	-2.2 %
Transportation and communication, electricity intensity	8.4 %	-2.5 %	0.9 %	-2.0 %	-0.5 %	0.0 %	0.0 %	0.0 %	1.0 %	1.0 %
Commercial, electricity intensity	3.4 %	0.4 %	0.3 %	-0.3 %	-0.5 %	-1.5 %	-2.0 %	-2.2 %	-2.2 %	-2.1 %
Residential electricity use (not intensity)	6.7 %	1.7 %	0.7 %	0.0 %	2.0 %	2.0 %	1.0 %	0.7 %	0.0 %	-0.5 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Energy (fuel use) intensity changes ktoe/mill.	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	2.5 %	-2.0 %	-1.5 %	0.3 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-0.9 %	-2.8 %	-4.8 %	5.3 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %
Transportation and communication, fuel intensity	-0.1 %	-4.5 %	-1.8 %	-2.1 %	-1.0 %	-2.0 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %
Commercial, fuel intensity	n.a.	n.a.	-5.5 %	-1.3 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %
Residential use (not intensity)	0.7 %	-6.4 %	-0.5 %	-2.5 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

Table 22. Assumptions of the LINDA Finland IND scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Finland IND			Scenario start year	2015	(2005-2026)		
Start years of periods	1974	1991	2001	2009	2015	2017	2021	2026	2031	2041
End years of periods	1990	2000	2008	2014	2016	2020	2025	2030	2040	2053
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
GDP	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry	0.9 %	0.4 %	1.0 %	-1.2 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Industry	2.6 %	4.7 %	4.2 %	-1.9 %	2.0 %	3.0 %	3.0 %	3.0 %	3.4 %	3.4 %
Transportation, communication	3.4 %	5.0 %	2.8 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.5 %	1.9 %	2.0 %	0.5 %	2.0 %	1.5 %	1.5 %	1.4 %	1.1 %	0.9 %
Total	3.1 %	3.0 %	2.8 %	-0.1 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Electricity intensity ktoe/million USD	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, electricity intensity	5.2 %	-1.3 %	9.1 %	-1.1 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %
Industry, electricity intensity	1.1 %	-1.1 %	-3.8 %	3.0 %	-1.0 %	-1.5 %	-1.5 %	-1.5 %	-1.5 %	-1.5 %
Transportation and communication, electricity intensity	8.4 %	-2.5 %	0.9 %	-2.0 %	-0.5 %	0.0 %	0.0 %	0.0 %	1.0 %	1.0 %
Commercial, electricity intensity	3.4 %	0.4 %	0.3 %	-0.3 %	0.0 %	-1.0 %	-1.5 %	-1.5 %	-1.5 %	-1.5 %
Residential electricity use (not intensity)	6.7 %	1.7 %	0.7 %	0.0 %	2.0 %	2.0 %	1.0 %	1.0 %	0.5 %	0.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Energy (fuel use) intensity changes ktoe/mill.	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	2.5 %	-2.0 %	-1.5 %	0.3 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-0.9 %	-2.8 %	-4.8 %	5.3 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %
Transportation and communication, fuel intensity	-0.1 %	-4.5 %	-1.8 %	-2.1 %	-1.0 %	-2.0 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %
Commercial, fuel intensity	n.a.	n.a.	-5.5 %	-1.3 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %	-3.0 %
Residential use (not intensity)	0.7 %	-6.4 %	-0.5 %	-2.5 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

The economic development in the scenarios are shown in following figures. The BAU and EFF scenarios have similar development, but in the IND scenario, the industrial sector is growing faster than in the other scenarios. The total growth of GDP is, however, same in all the scenarios in order to make them comparable (Figure 7).

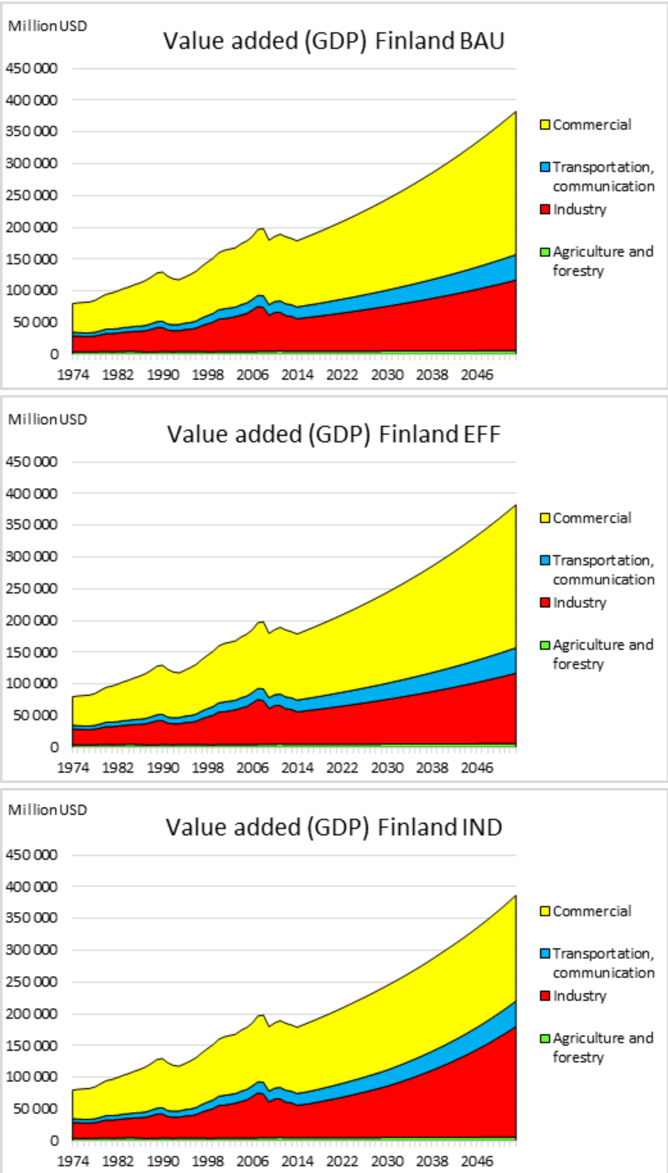

Figure 7. Assumed economic growth in the LINDA Finland BAU, EFF and IND scenarios.

The electricity consumption varies considerably in the different scenarios (Figure 8). Electricity consumption continues to grow in the BAU scenario in all economic sectors, mainly due to the assumed fast economic growth. In the EFF scenario, electricity consumption starts to decline due to improved electricity efficiency in the industrial and commercial sectors. In addition, growth in household electricity consumption is assumed to slow down, and start to decrease because of new energy saving appliances. In the IND scenario, electricity consumption continues to grow considerably due to fast economic growth in the industrial sector, where electricity intensity is the highest. Even though total economic growth is the same as in the BAU scenario, electricity demand will be much higher in the IND scenario.

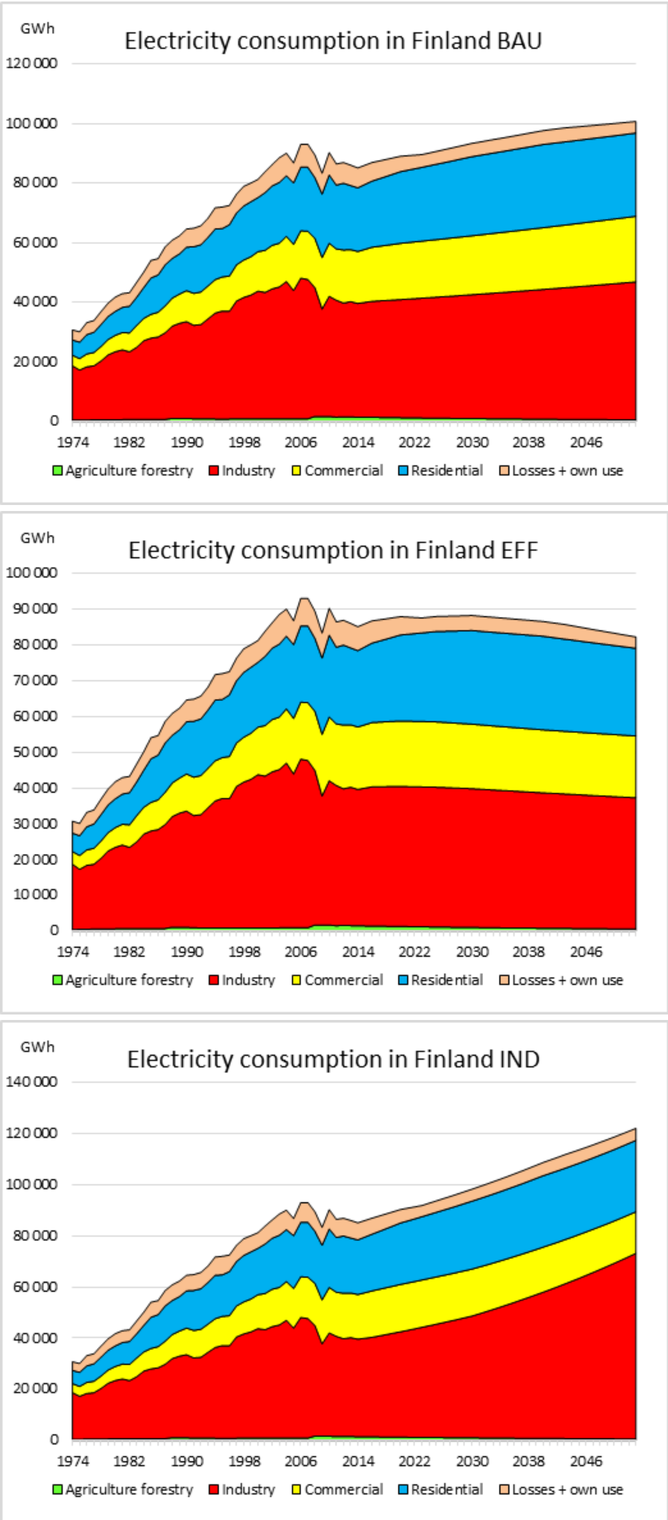

Figure 8. Electricity consumption in the LINDA Finland BAU, EFF and IND scenarios.

The sectoral final energy use in the LINDA Finland scenarios is shown in Figure 9. Differences between the scenarios in final energy consumption are smaller than in electricity consumption, because fuel intensities were assumed to improve in a similar way in all scenarios.

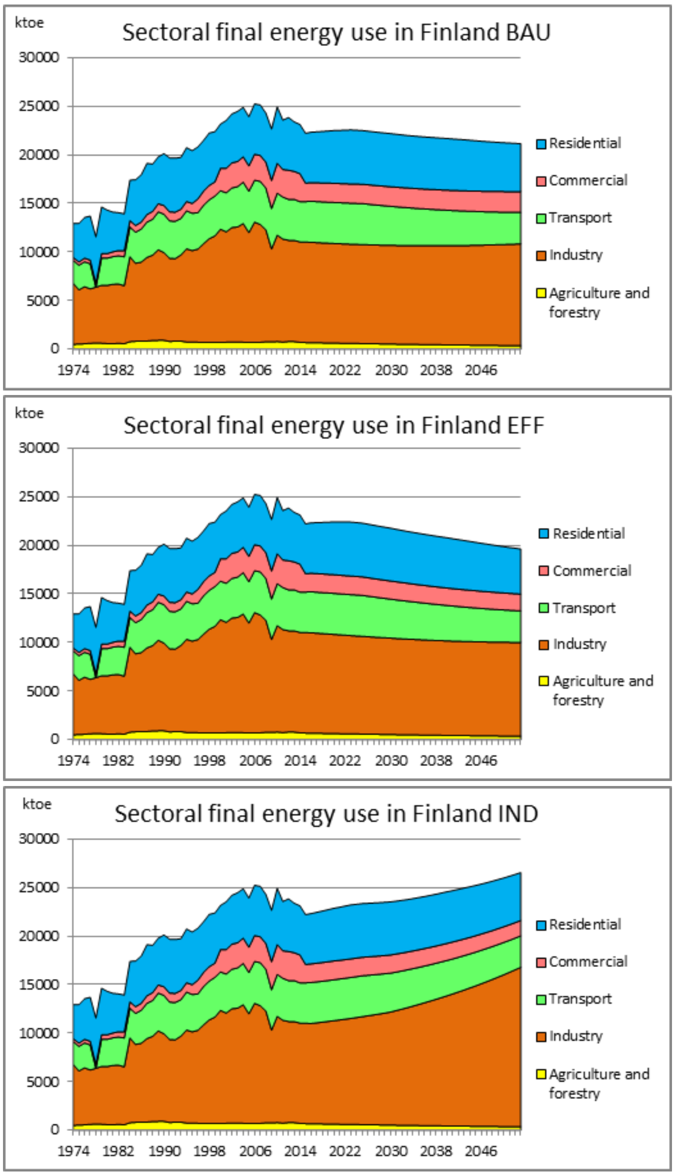

Figure 9. Final energy consumption in the LINDA Finland BAU, EFF and IND scenarios.

Figure 10 shows the use of different fuels in the LINDA Finland scenarios. The share of fuels used in different sectors were assumed to be similar in all scenarios. The main difference comes from fuel use in power generation. In all scenarios, it is assumed that the share of biofuels is increasing considerably due to the climate policy measures in Finland. This means an assumption that fossil fuels are in many cases replaced by biofuels (e.g. biodiesel). Traditional use of peat in Finnish CHP plants is assumed to continue, especially in the IND scenario. The se of fossil fuels is assumed to be reduced in all scenarios, as a result of climate policy measures and reduction of prices of alternative electricity production technologies (mainly solar and wind). In all scenarios, the amount of solar and wind power investments is assumed to be identical. Reduction in the use of fossil fuel is the fastest in the LINDA Finland EFF scenario (Figure 10). In this scenario, electricity demand is lower than in other scenarios, and carbon-neutral production can fulfil most of the energy needed by the year 2050. In the BAU scenario, investments in carbon-neutral production are not large enough and natural gas remains as a significant power source. In the IND scenario, electricity consumption is so large that carbon-neutral energy sources cannot produce all the needed electricity, and thus coal, peat, and natural gas are needed in the existing power plants for electricity production. Some fossil fuels are still used in the transport sector in all LINDA Finland scenarios.

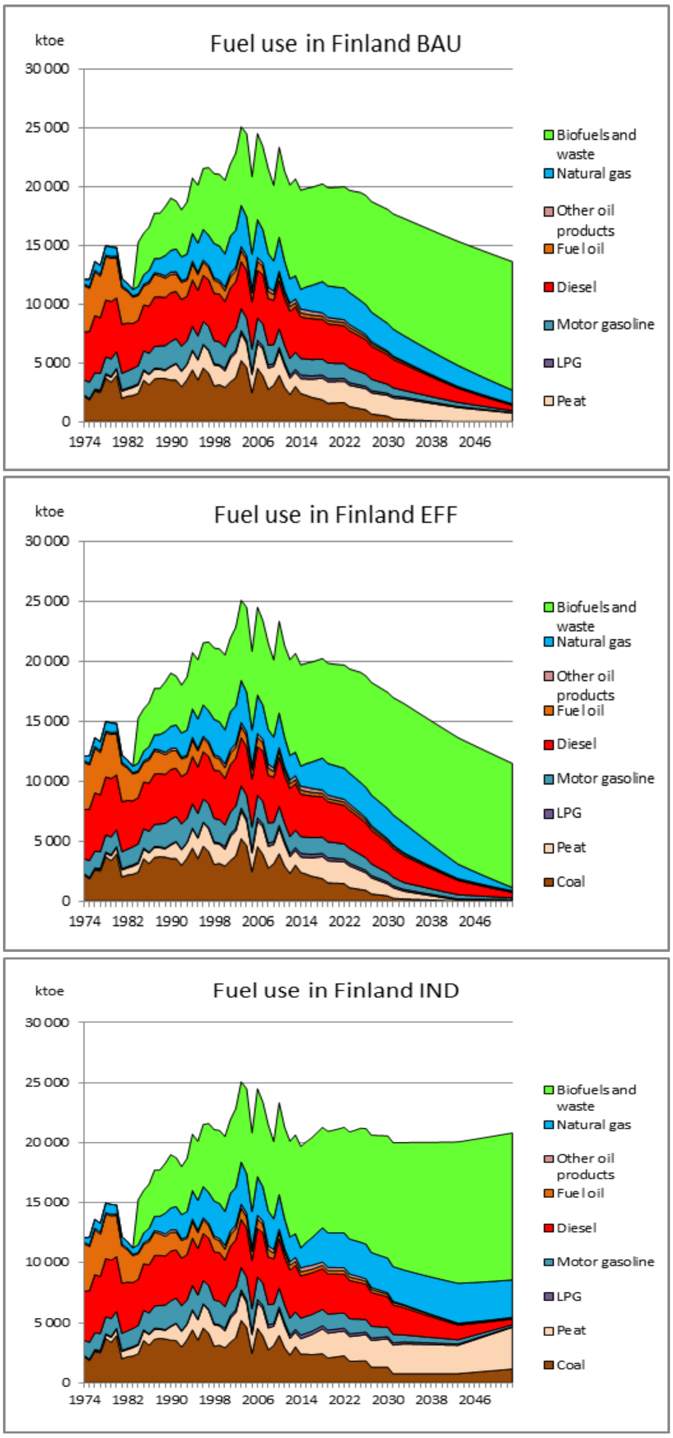

Figure 10. Use of fuels in the LINDA Finland BAU; EFF and IND scenarios.

In Figures 11-13, energy use in different sectors of the economy is presented; i.e. industrial (Figure 11), commercial (Figure 12), and residential sectors (Figure 13).

In the LINDA Finland EFF scenario, industrial electricity use is smaller than in the BAU scenario because of improved efficiency (Figure 11). In the IND scenario, industrial energy use (biofuels and electricity) increases considerably due to the fast growth of industrial output.

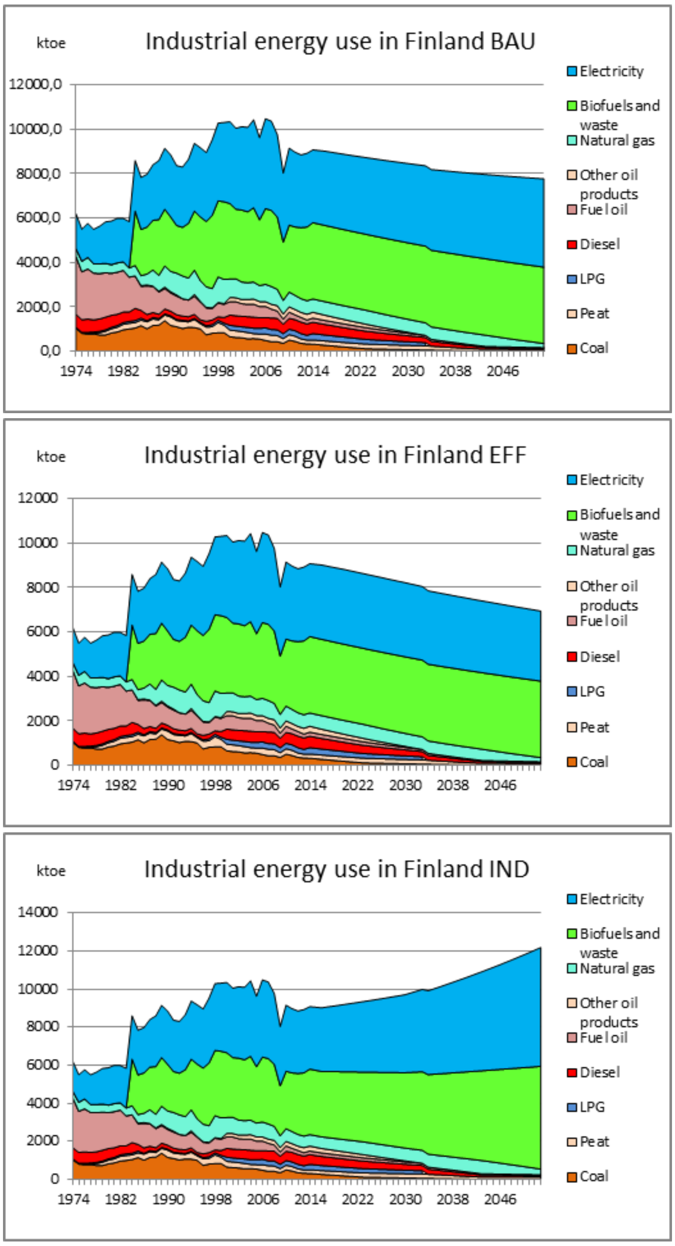

Figure 11. Energy use in the industrial sector in the LINDA Finland BAU, EFF and IND scenarios.

Energy use in the commercial sector in the different LINDA Finland scenarios is shown in Figure 12. In the IND scenario, energy use in the commercial sector is the smallest, because economic growth is focused on the industrial sector. In the EFF scenario, energy use in commercial sector starts to decrease because efficiency improvements cancel the impacts of economic growth. In the commercial sector, energy consumption is mainly electricity consumption.

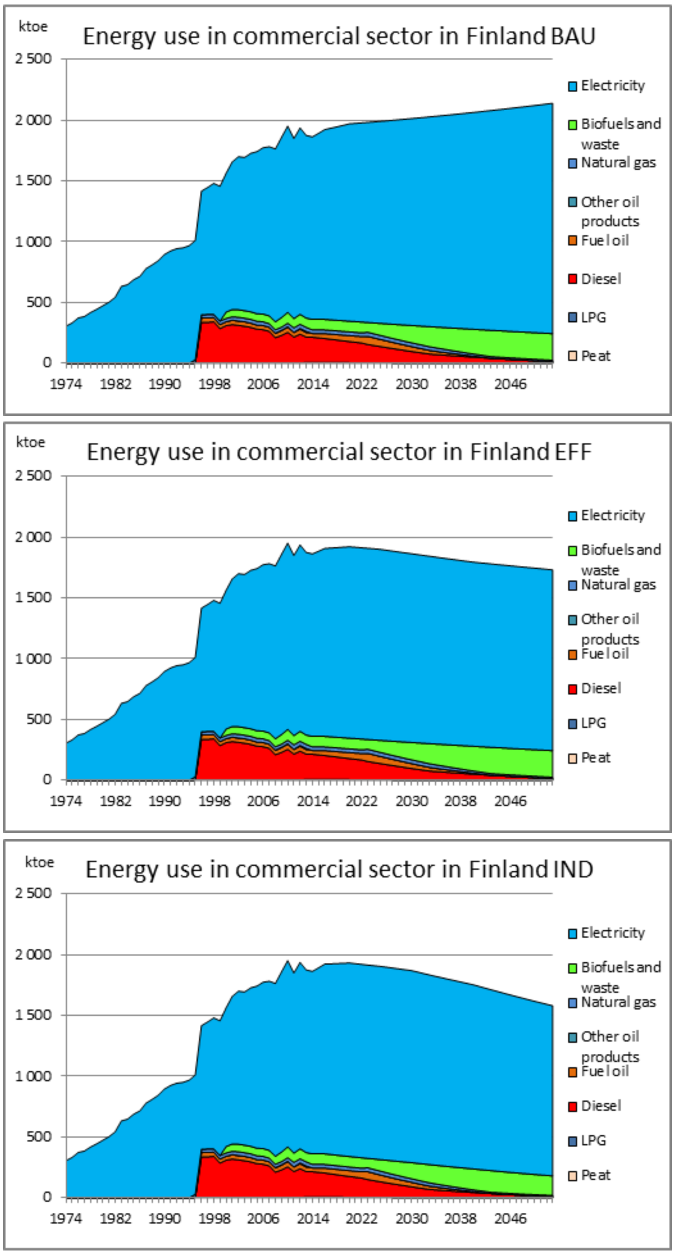

Figure 12. Energy use in the commercial sector in the LINDA Finland BAU, EFF and IND scenarios.

Energy use in the residential sector in different LINDA Finland scenarios is shown in Figure 13. In the EFF scenario, residential electricity use grows more slowly than in the BAU scenario and starts to decline due to the assumed fast introduction of more efficient appliances. Biofuels are assumed to be used in the residential sector, mainly for heating of the detached houses.

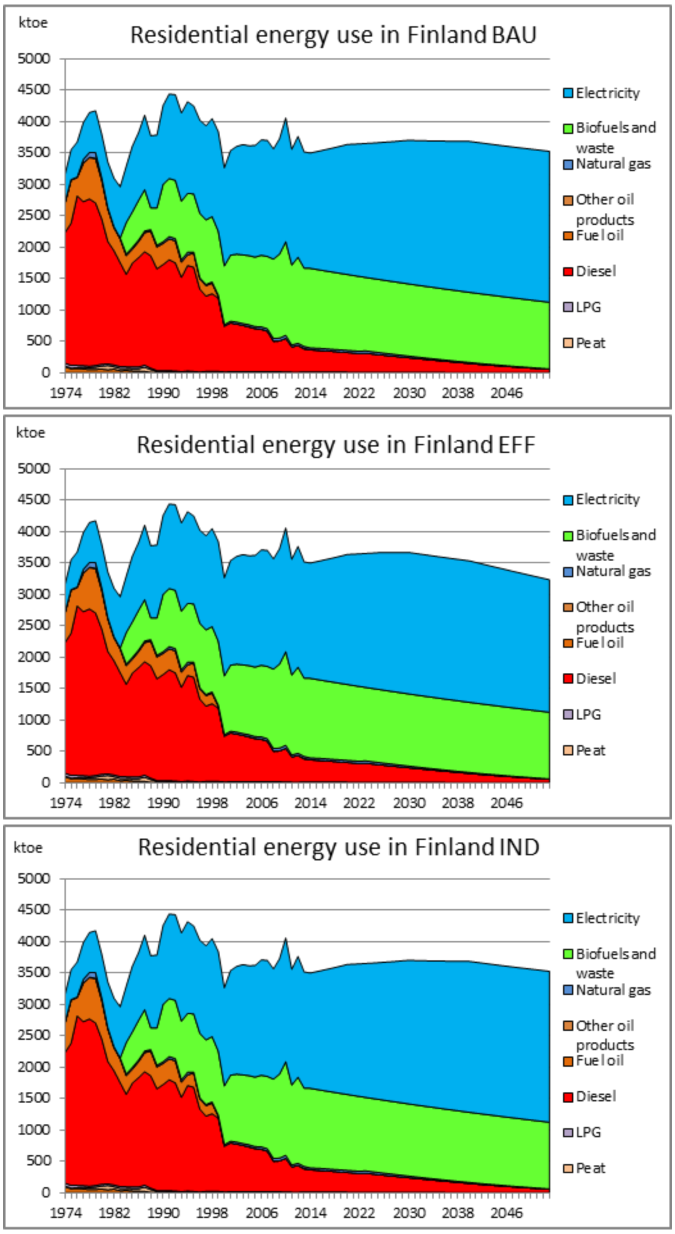

Figure 13. Energy use in the residential sector in the LINDA Finland BAU, EFF and IND scenarios.

The CO_2 emissions follow the path of use of different fossil fuels in all scenarios (Figure 14). The emissions decrease almost to zero in the EFF scenario, and decrease significantly also in the BAU scenario. In the IND scenario, the decrease of CO_2 emissions is smaller than in other scenarios, because the use of peat, coal and natural gas continues in CHP plants, and the use of peat even increases after the year 2040. The development of CO_2 emissions from fossil fuel combustion is very sensitive to the assumptions on economic growth in different sectors, fuel intensity in different sectors, power plant capacity (including investments and phase-outs), and capacity factors of different power plant types.

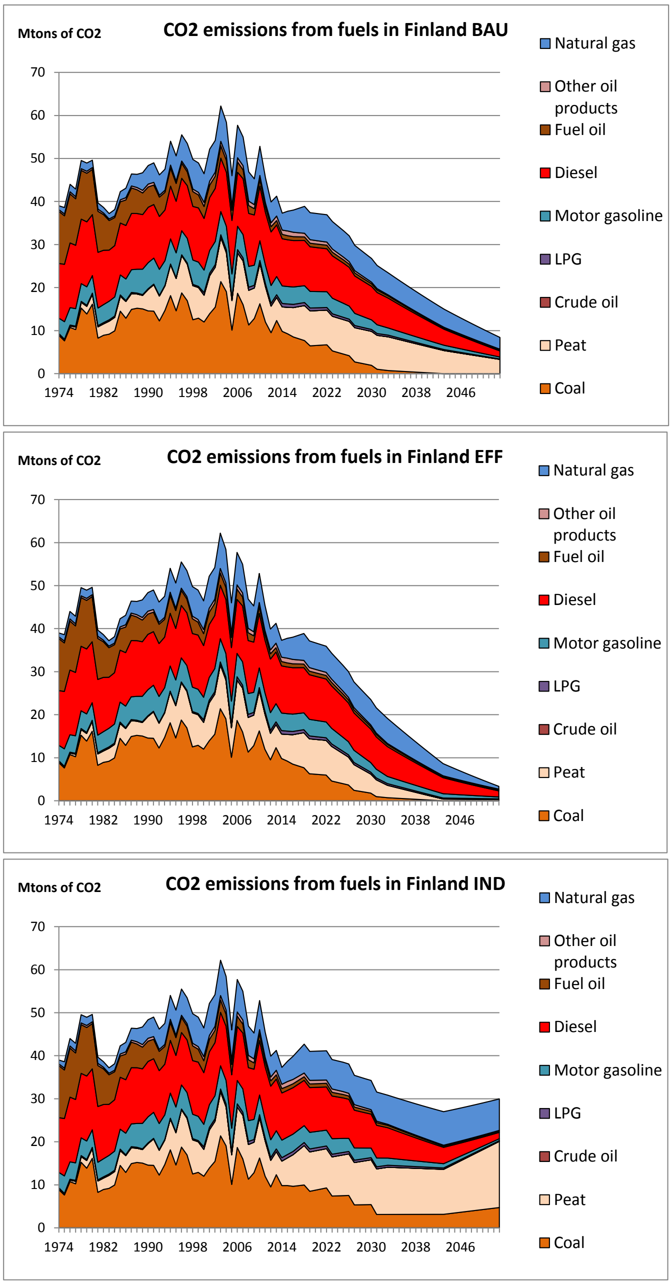

Figure 14. CO_2 emissions in the LINDA Finland BAU, EFF and IND scenarios.

In the different LINDA Finland scenarios, electricity production is planned in a way that the needed electricity imports (import = demand minus production) is similar in order to make the scenarios comparable. This is achieved by changing the power plant capacity factors in the fossil fuel power plants. The installed power plant capacities are similar in all the scenarios.

The electricity import in the LINDA Finland scenarios is shown in Figure 15. In all scenarios, electricity imports decrease until the year 2026 and start to increase again almost reaching the current level by the year 2050. Differences between the BAU, EFF and IND scenarios are marginal.

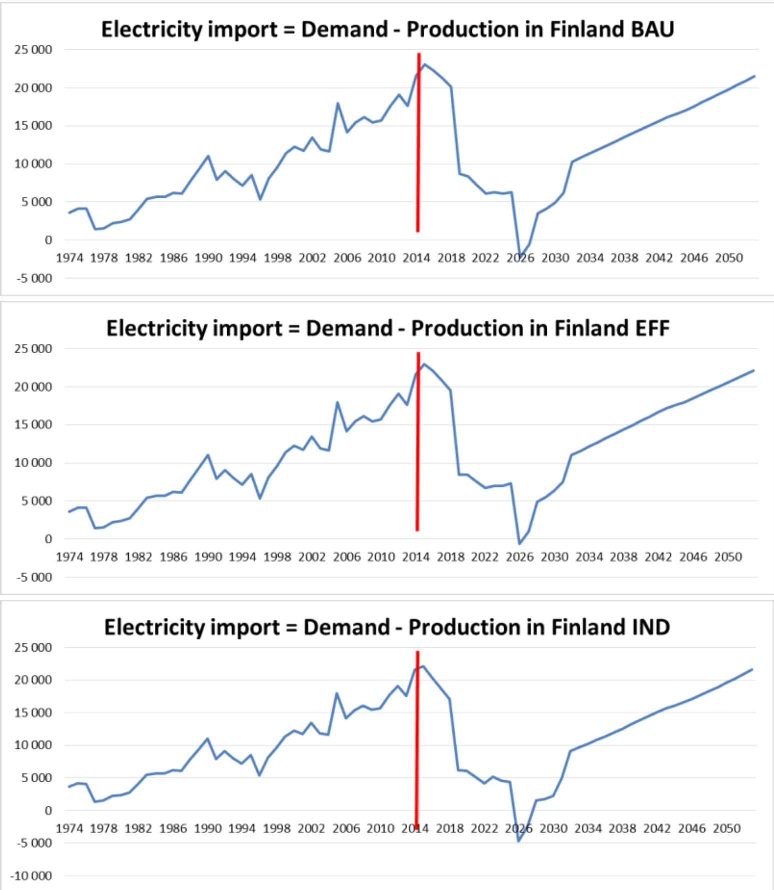

Figure 15. Electricity imports in the LINDA Finland BAU, EFF and IND scenarios.

The installed power plant capacity is the same in all LINDA Finland scenarios (Figure 16). The assumed addition to the Finnish nuclear capacity comes from the Olkiluoto 3 and Hanhikivi 1 plants (under construction), but also the phase-out of Loviisa 1 and 2 are taken into account. Phase-out of old coal-fired plants are also taken into account. Assumed additions to wind and solar power capacities are considerable.

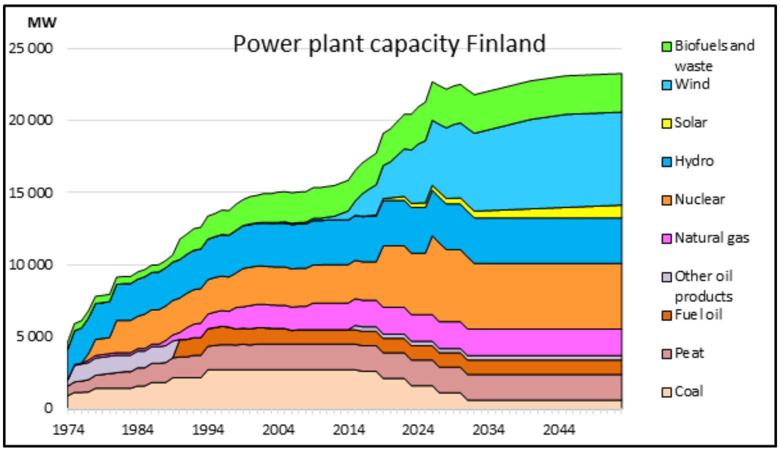

Figure 16. Power plant capacity in the LINDA Finland scenarios.

The energy intensity development in the different LINDA Finland scenarios is illustrated in Figure 17. All indicators (TPES/GDP, FEC/GDP and TPES/FEC) have their highest values in the case of the IND scenario, due to the increasing industrial energy demand. The values are the lowest in the case of the EFF scenario and the BAU scenarios falls between. Final energy intensity (FEC/GDP) of the BAU and EFF scenarios are quite close to each other.

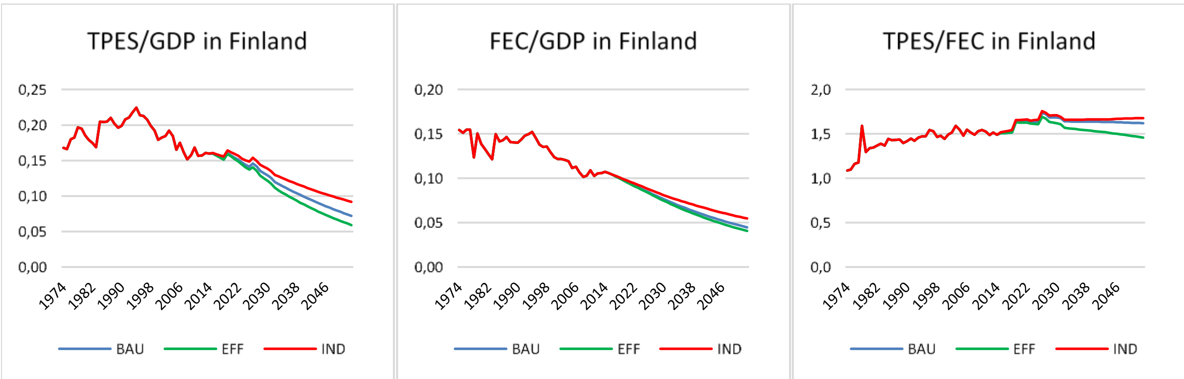

Figure 17. Primary energy intensity (TPES/GDP), final energy intensity and the ratio of TPES/FEC in the LINDA Finland BAU, EFF and IND scenarios.

The indicator primary energy divided by final energy (TPES/FEC; Figure 17) should describe the efficiency of the energy transformation system. In practice, it is affected most by switches between the use of different energy sources. Increasing use of renewable energy sources such as wind and solar, improves the value of this indicator because these renewables are calculated as primary energy by multiplying the amount of produced electricity with a coefficient 1, so in their case TPES=FEC. For nuclear power the coefficient is 3 (because of low thermal efficiency), so increased use of nuclear power would increase the value of the indicator TPES/FEC without any change in “real” efficiency in electricity production.

In all the LINDA Finland scenarios, TPES/FEC is increasing when new nuclear power plants are taken in production. The TPES/FEC indicator decreases later due to increased share of wind and solar power (where TPES=FEC) and decreased share of fossil energy use (with lower efficiency, i.e. higher value of TPES/FEC). In the EFF scenario, the share of wind and solar in the total energy production is the highest due to lower electricity demand, and this decreases the TPES/FEC indicator value.

Energy efficiency improvements (decrease in energy intensity, TPES/GDP) in different LINDA Finland scenarios by the year 2030 can be compared to different base year figures (Figure 18). We have used in the calculations three different base years 1990, 2005 and 2010. Efficiency improvement is in all cases the largest in the EFF scenario, because of a fast decrease in energy consumption. Energy efficiency improvements by 2030 are the largest when compared to the 1990 value, when energy consumption was the highest among the base years. Improvements are larger when compared to 2010 than when compared to 2005, due to a small local "peak" in primary energy intensity (TPES/GDP), as a result of low GDP in 2010 which was related to the financial crisis.

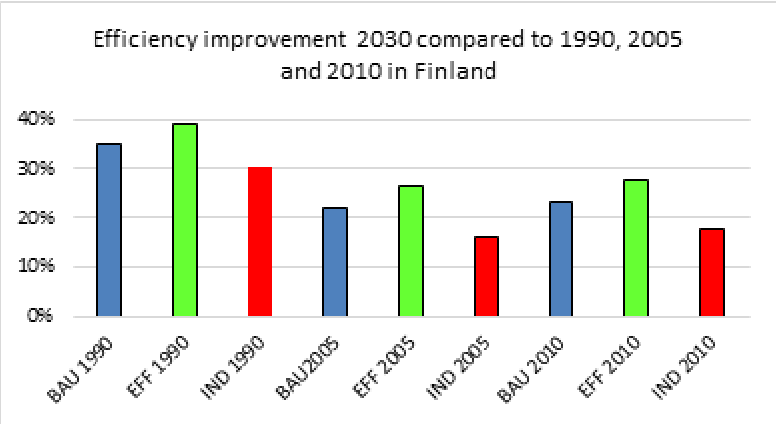

Figure 18. Improvements in energy efficiency in the LINDA Finland BAU, EFF and IND scenarios, primary energy intensity (TPES/GDP) value in 2030 in comparison to values in 1990, 2005 and 2010.

Germany

Scenario "LINDA Germany BAU" (Table 23) is a baseline scenario, where past trends of economic development and electricity intensity continue. The fuel intensity changes are assumed to be similar to the BAU scenario in all other scenarios. Tables 23-25 show the assumptions for economic development and the assumed changes in electricity and fuel efficiencies for the LINDA BAU, EFF and IND scenarios for Germany.

Scenario "LINDA Germany EFF" (Table 24) is an energy efficiency scenario, which has similar economic growth figures for all sectors (agriculture and forestry, industry, transportation and communication, and commercial) to the BAU scenario. In the EFF scenario, electricity intensity in the industrial and commercial sectors is assumed to improve faster than in the BAU scenario. In transport and communications sector, electricity intensity of the EFF scenario is the same as in the BAU scenario. In this sector, electricity intensity is assumed to increase in the future with a shift to more electrical vehicles.

Scenario "LINDA Germany IND" (Table 25) is an industrial scenario with fast economic growth figures for industry and lower growth rate for commercial sector than in the BAU and EFF scenarios. This means that the IND scenario assumes a structural change in the economy, towards more industry-driven development. The electricity intensity figures in the IND scenario are similar to the BAU scenario, so this scenario is analyzing the impact of structural change in the economy, and the possible restrictions caused by it.

Table 23. Assumptions of the LINDA Germany BAU scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		*Country name*	Germany BAU		*Scenario start year*		2015	*(2005-2026)*		
Start years of periods	1974	1991	2001	2009	2015	2017	2021	2026	2031	2041
End years of periods	1990	2000	2008	2014	2016	2020	2025	2030	2040	2053
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
GDP	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry	1.3 %	-3.9 %	4.6 %	-4.6 %	0.0 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Industry	1.2 %	0.1 %	1.3 %	4.3 %	1.5 %	1.5 %	2.0 %	2.0 %	2.0 %	2.0 %
Transportation, communication	2.7 %	3.0 %	4.2 %	2.6 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.3 %	2.5 %	1.0 %	0.5 %	1.5 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Total	2.4 %	1.7 %	1.4 %	1.7 %	1.5 %	1.8 %	2.0 %	2.0 %	2.0 %	2.0 %
					1.5	2	2.5	3		
					1.5 %	1.8 %	2.0 %	2.0 %	2.0 %	2.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Electricity intensity ktoe/million USD	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, electricity intensity	-100.0 %	n.a.	n.a.	n.a.	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, electricity intensity	-0.2 %	-0.2 %	-0.3 %	-2.3 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Transportation and communication, electricity intensity	-0.7 %	-2.5 %	-9.2 %	-2.1 %	1.0 %	0.0 %	0.0 %	0.0 %	1.0 %	1.0 %
Commercial, electricity intensity	1.4 %	-0.3 %	0.8 %	-0.1 %	0.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %
Residential electricity use (not intensity)	3.1 %	0.7 %	0.6 %	-0.5 %	2.0 %	2.0 %	1.0 %	1.0 %	0.3 %	0.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Energy (fuel use) intensity changes ktoe/mill.	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	-1.8 %	-3.2 %	-100.0 %	n.a.	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-3.5 %	-2.5 %	-0.7 %	-3.0 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %
Transportation and communication, fuel intensity	0.2 %	-2.2 %	-5.1 %	-1.9 %	-1.0 %	-2.0 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %
Commercial, fuel intensity	-3.3 %	-5.9 %	1.0 %	2.4 %	-2.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %
Residential use (not intensity)	0.0 %	0.1 %	-2.4 %	0.7 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

Table 24. Assumptions of the LINDA Germany EFF scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Germany EFF			Scenario start year	2015	(2005-2026)		
Start years of periods	1974	1991	2001	2009	2015	2017	2021	2026	2031	2041
End years of periods	1990	2000	2008	2014	2016	2020	2025	2030	2040	2053
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
GDP	1974-1990	1991-2000	2001-2008	2009-2014	2015-2016	2017-2020	2021-2025	2026-2030	2031-2040	2041-2053
Agriculture and forestry	1.3 %	-3.9 %	4.6 %	-4.6 %	0.0 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Industry	1.2 %	0.1 %	1.3 %	4.3 %	1.5 %	1.5 %	2.0 %	2.0 %	2.0 %	2.0 %
Transportation, communication	2.7 %	3.0 %	4.2 %	2.6 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.3 %	2.5 %	1.0 %	0.5 %	1.5 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Total	2.4 %	1.7 %	1.4 %	1.7 %	1.5 %	1.8 %	2.0 %	2.0 %	2.0 %	2.0 %
					1.5	2	2.5	3		
					1.5 %	1.8 %	2.0 %	2.0 %	2.0 %	2.0 %
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
Electricity intensity ktoe/million USD	1974-1990	1991-2000	2001-2008	2009-2014	2015-2016	2017-2020	2021-2025	2026-2030	2031-2040	2041-2053
Agriculture and forestry, electricity intensity	-100.0 %	n.a.	n.a.	n.a.	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, electricity intensity	-0.2 %	-0.2 %	-0.3 %	-2.3 %	-1.5 %	-2.5 %	-2.5 %	-2.5 %	-2.5 %	-2.5 %
Transportation and communication, electricity intensity	-0.7 %	-2.5 %	-9.2 %	-2.1 %	1.0 %	0.0 %	0.0 %	0.0 %	1.0 %	1.0 %
Commercial, electricity intensity	1.4 %	-0.3 %	0.8 %	-0.1 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Residential electricity use (not intensity)	3.1 %	0.7 %	0.6 %	-0.5 %	1.5 %	1.5 %	0.8 %	0.7 %	0.4 %	-0.5 %
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
Energy (fuel use) intensity changes ktoe/mill.	1974-1990	1991-2000	2001-2008	2009-2014	2015-2016	2017-2020	2021-2025	2026-2030	2031-2040	2041-2053
Agriculture and forestry, fuel intensity	-1.8 %	-3.2 %	-100.0 %	n.a.	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-3.5 %	-2.5 %	-0.7 %	-3.0 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %
Transportation and communication, fuel intensity	0.2 %	-2.2 %	-5.1 %	-1.9 %	-1.0 %	-2.0 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %
Commercial, fuel intensity	-3.3 %	-5.9 %	1.0 %	2.4 %	-2.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %
Residential use (not intensity)	0.0 %	0.1 %	-2.4 %	0.7 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

Table 25. Assumptions of the LINDA Germany IND scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Germany IND			Scenario start year	2015	(2005-2026)		
Start years of periods	1974	1991	2001	2009	2015	2017	2021	2026	2031	2041
End years of periods	1990	2000	2008	2014	2016	2020	2025	2030	2040	2053
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
GDP	1974-1990	1991-2000	2001-2008	2009-2014	2015-2016	2017-2020	2021-2025	2026-2030	2031-2040	2041-2053
Agriculture and forestry	1.3 %	-3.9 %	4.6 %	-4.6 %	0.0 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Industry	1.2 %	0.1 %	1.3 %	4.3 %	2.0 %	2.5 %	3.0 %	3.0 %	3.0 %	3.0 %
Transportation, communication	2.7 %	3.0 %	4.2 %	2.6 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.3 %	2.5 %	1.0 %	0.5 %	1.2 %	1.4 %	1.4 %	1.4 %	1.4 %	1.2 %
Total	2.4 %	1.7 %	1.4 %	1.7 %	1.5 %	1.8 %	2.0 %	2.0 %	2.0 %	2.0 %
					1.5	2	2.5	3		
					1.5 %	1.8 %	2.0 %	2.0 %	2.0 %	2.0 %
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
Electricity intensity ktoe/million USD	1974-1990	1991-2000	2001-2008	2009-2014	2015-2016	2017-2020	2021-2025	2026-2030	2031-2040	2041-2053
Agriculture and forestry, electricity intensity	-100.0 %	n.a.	n.a.	n.a.	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, electricity intensity	-0.2 %	-0.2 %	-0.3 %	-2.3 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Transportation and communication, electricity intensity	-0.7 %	-2.5 %	-9.2 %	-2.1 %	1.0 %	0.0 %	0.0 %	0.0 %	1.0 %	1.0 %
Commercial, electricity intensity	1.4 %	-0.3 %	0.8 %	-0.1 %	0.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %
Residential electricity use (not intensity)	3.1 %	0.7 %	0.6 %	-0.5 %	2.0 %	2.0 %	1.0 %	1.0 %	0.5 %	0.0 %
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
Energy (fuel use) intensity changes ktoe/mill.	1974-1990	1991-2000	2001-2008	2009-2014	2015-2016	2017-2020	2021-2025	2026-2030	2031-2040	2041-2053
Agriculture and forestry, fuel intensity	-1.8 %	-3.2 %	-100.0 %	n.a.	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-3.5 %	-2.5 %	-0.7 %	-3.0 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %
Transportation and communication, fuel intensity	0.2 %	-2.2 %	-5.1 %	-1.9 %	-1.0 %	-2.0 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %
Commercial, fuel intensity	-3.3 %	-5.9 %	1.0 %	2.4 %	-2.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %	-3.5 %
Residential use (not intensity)	0.0 %	0.1 %	-2.4 %	0.7 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

Figure 19 shows economic development per sector in the LINDA Germany scenarios based on the assumptions presented in Tables 24-26 above. The BAU and EFF scenarios have a similar development, but the IND scenario has a faster growth in the industrial sector. The total GDP growth is, however, the same in all scenarios in order to make them more comparable to each other.

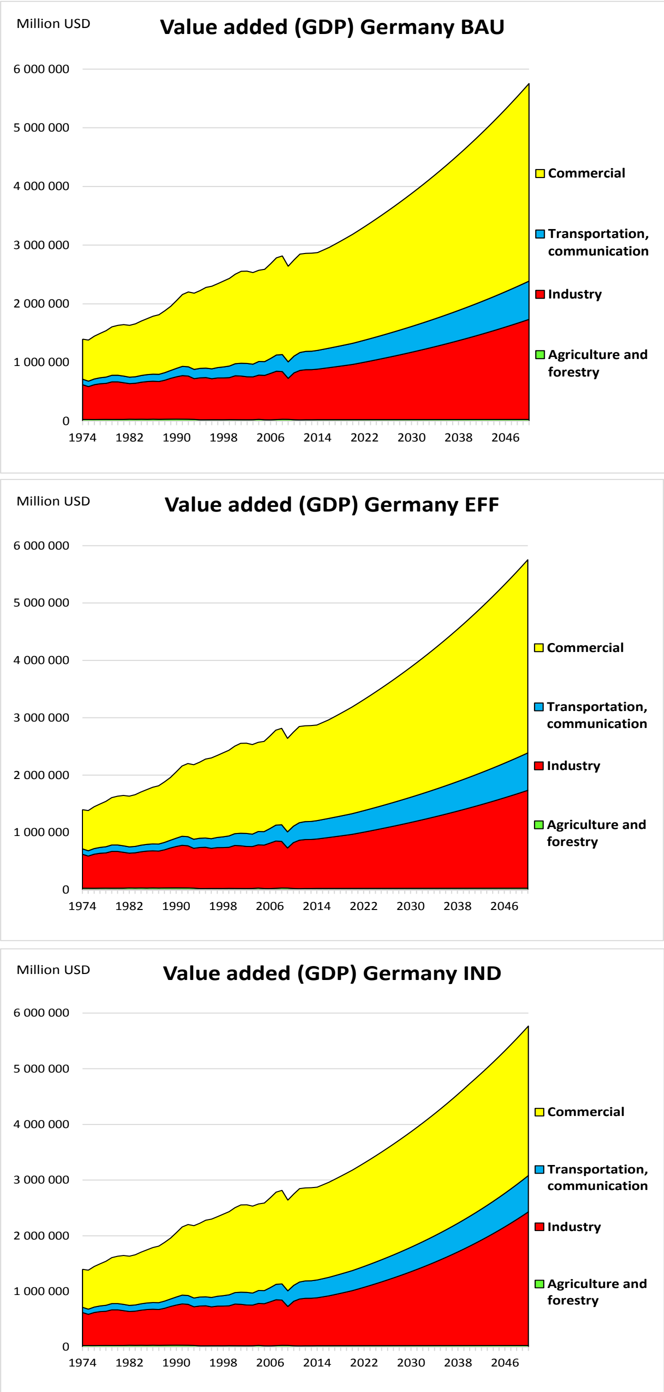

Figure 19. Assumed economic growth in different sectors in the LINDA Germany BAU, EFF and IND scenarios.

Electricity consumption varies considerably in the LINDA Germany BAU, EFF and IND scenarios (Figure 20). The consumption continues to grow in the BAU scenario in all sectors, mainly due to the assumed fast economic growth. In the EFF scenario, electricity consumption decreases due to improved electricity efficiency in the industrial and commercial sectors. In addition, in this scenario consumption of electricity in households is assumed to slow down, and it starts to decrease because new energy saving appliances will be taken widely into use.

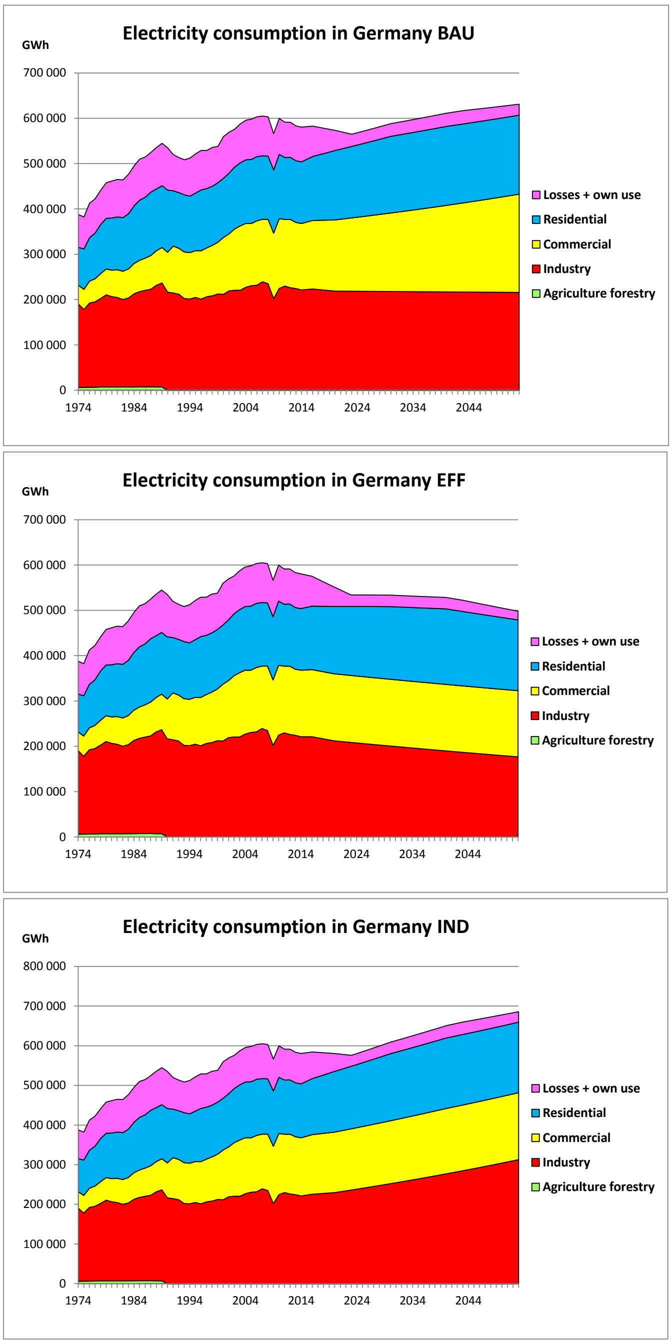

Figure 20. Electricity consumption in different sectors in the LINDA Germany BAU, EFF and IND scenarios.

In the IND scenario, electricity consumption continues to grow considerably due to the fast economic growth in the electricity intensive industrial sector. Even though total economic growth in the IND scenario is equal to the BAU scenario, electricity demand will be much higher in the IND scenario.

The sectoral final energy use in the German scenarios can be observed in Figure 21. The difference between final energy consumption in the scenarios is smaller as the difference in electricity consumption (Figure 20), because assumption on change in fuel intensity in the different scenarios were similar (see Tables 23-25).

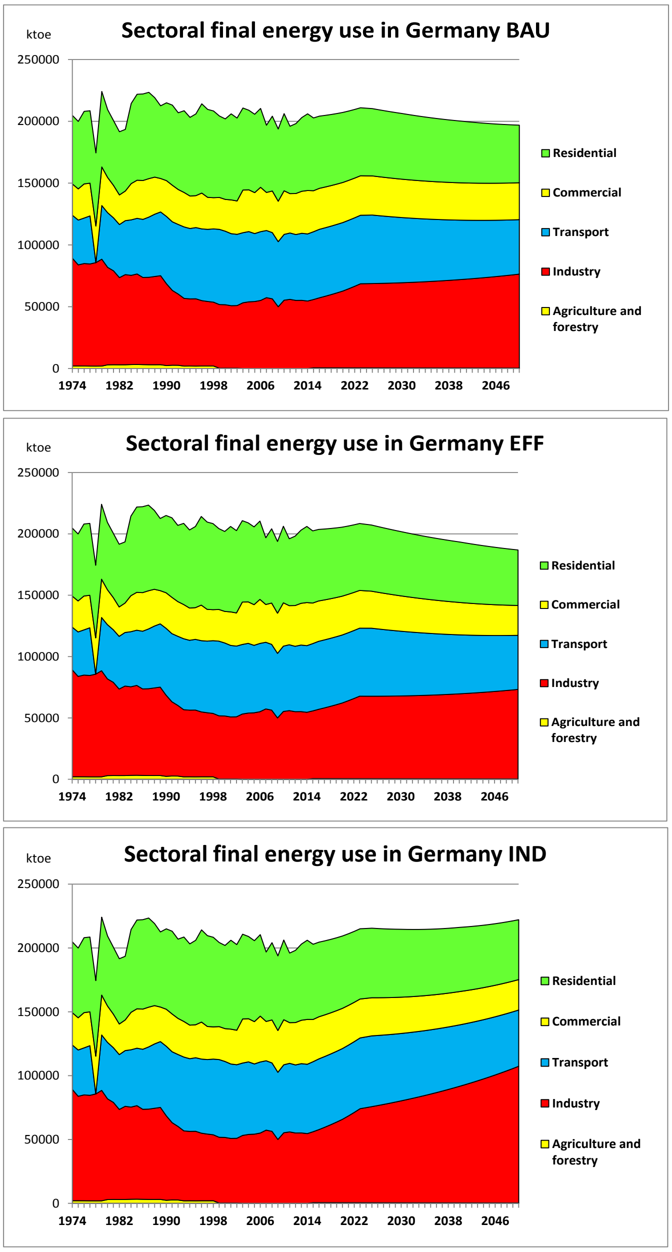

Figure 21. Final energy use in different sectors in the LINDA Germany BAU, EFF and IND scenarios.

Shares of the fuel use in different economic sectors in the LINDA Germany BAU, EFF and IND scenarios were assumed to be similar (Figure 22). The main difference comes from the fuel use in power generation. In all the scenarios, the share of biofuels is assumed to increase considerably due to the climate policy measures. This means that fossil fuels are in many cases replaced by biofuels such as biodiesel. Decrease of fossil fuel use is the fastest in the EFF scenario, because electricity demand is low and carbon-free sources fulfil most of the needed production by 2050. In the BAU scenario, carbon-free production almost stops the use of fossil energy by 2050. In the IND scenario, electricity consumption is the largest and carbon-free sources cannot produce all the needed electricity and natural gas (in the existing plants) is still needed.

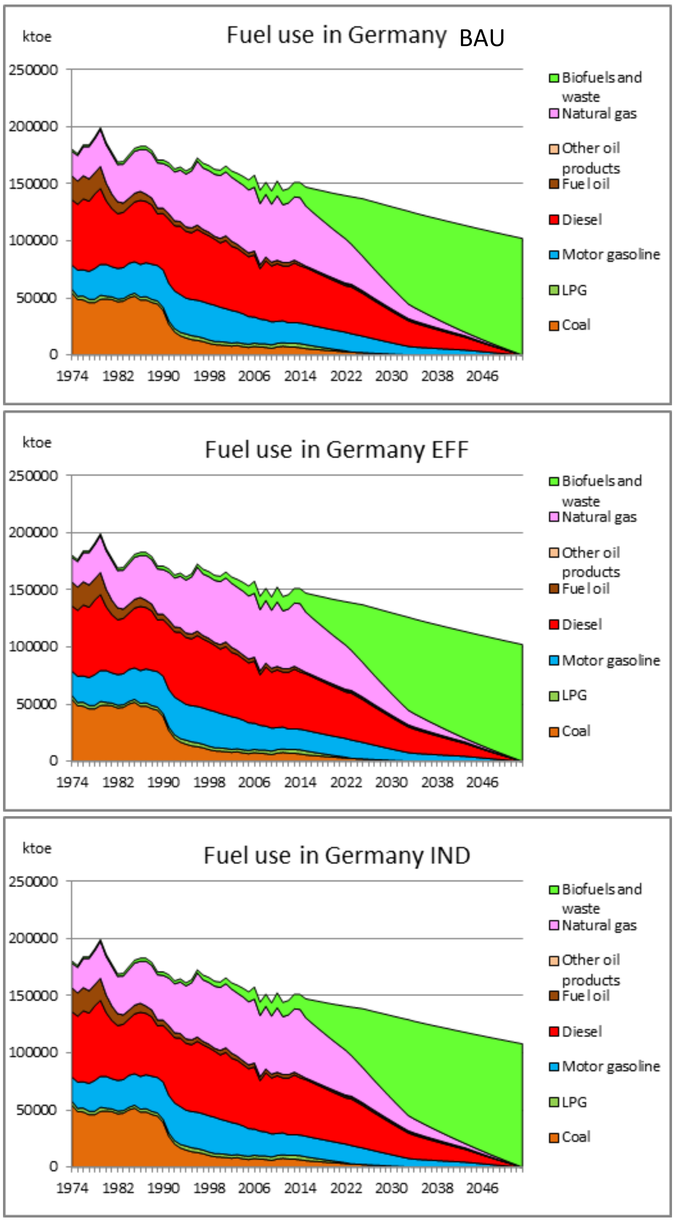

Figure 22. Use of fuels in different sectors in the LINDA Germany BAU, EFF and IND scenarios.

In the LINDA Germany EFF scenario, industrial electricity use is smaller than in the BAU scenario because of improved efficiency (Figure 23). In the IND scenario the industrial energy use increases considerably due to the fast growth of industrial output. In all scenarios, the use of fossil fuels decreases and stops by the end of the projected period.

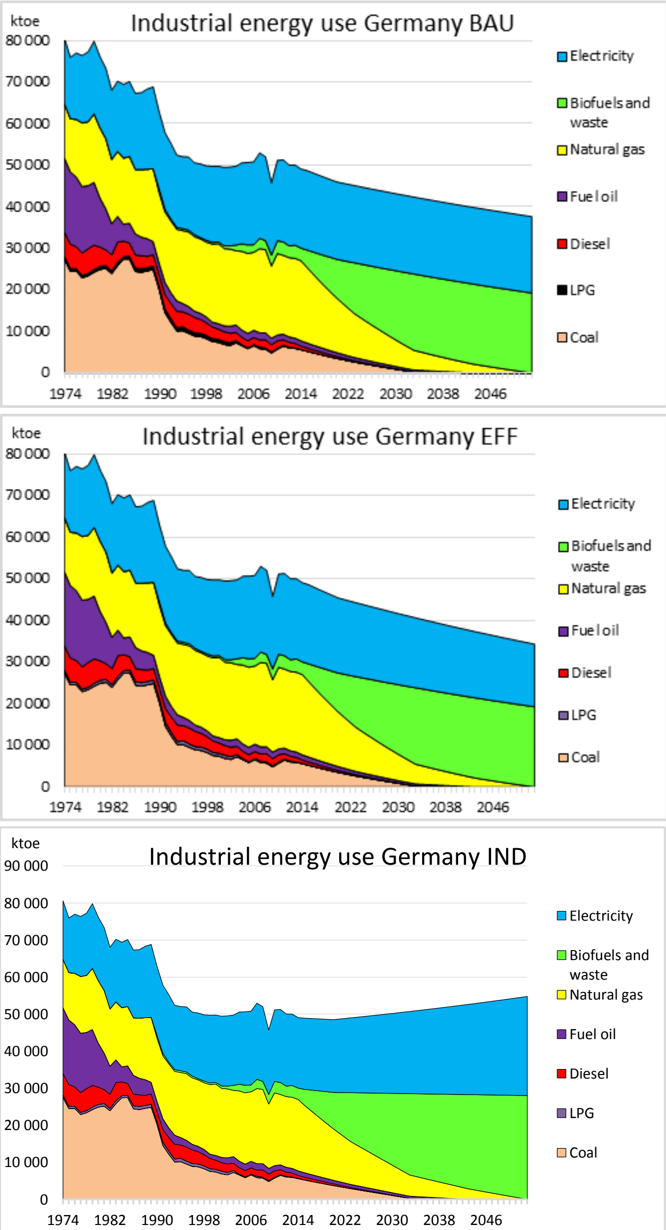

Figure 23. Energy use in the industrial sector in the LINDA Germany BAU, EFF and IND scenarios.

Energy use in commercial sector in the German scenarios is shown in Figure 24. In the IND scenario, energy use in the commercial sector is the smallest, because economic growth in this sector is not fast as in the other scenarios. In the EFF scenario, energy use in commercial sector starts to decrease because efficiency improvements cancel the impacts of economic growth. In the commercial sector, energy consumption is mainly electricity consumption.

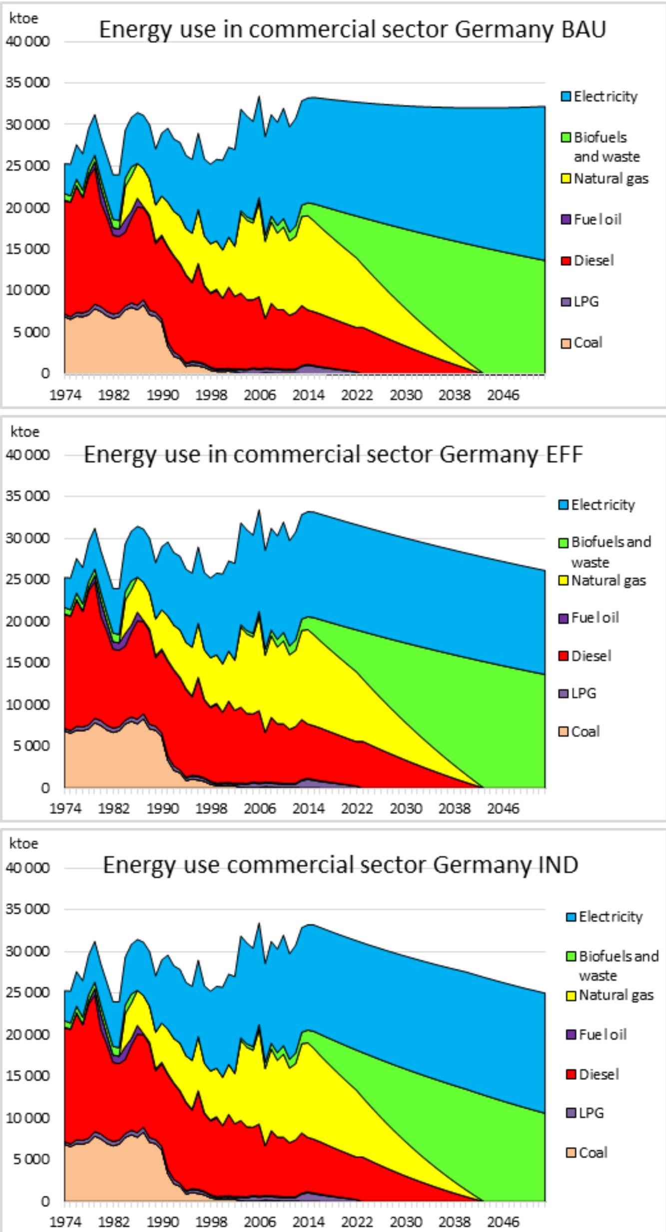

Figure 24. Energy use in the commercial sector in the LINDA Germany BAU, EFF and IND scenarios.

Figure 25 shows that in the EFF scenario, residential electricity use grows more slowly than in the BAU scenario. This is due to the assumed faster introduction of more efficient electrical appliances in the German households.

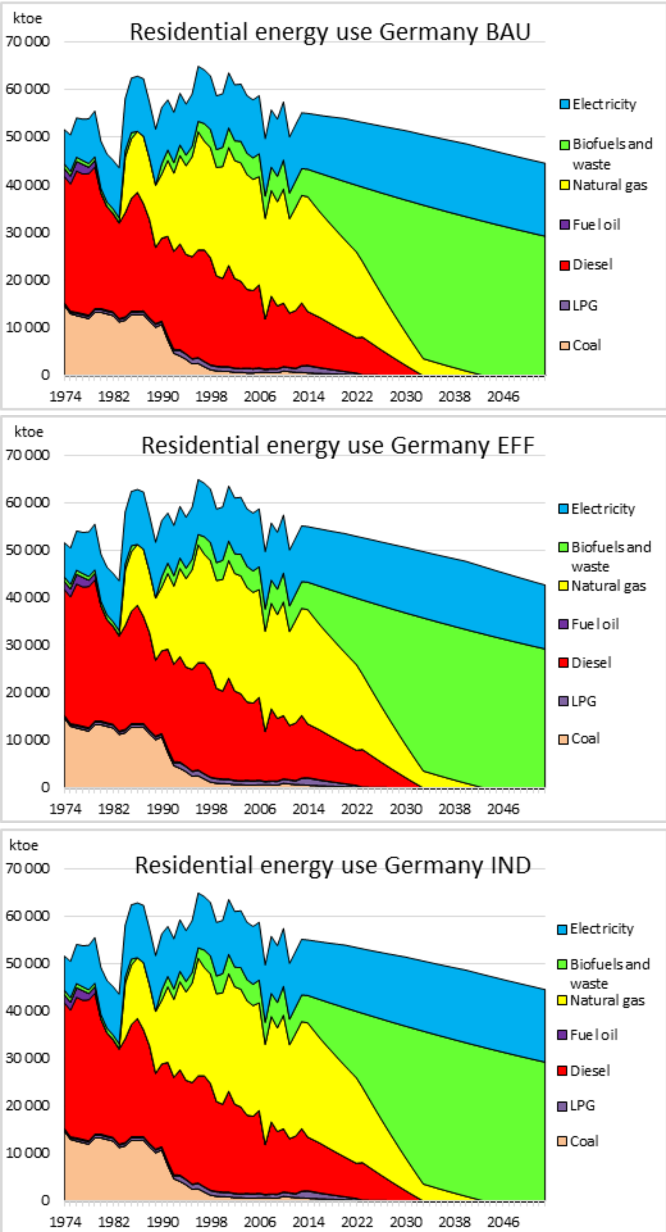

Figure 25. Energy use in the residential sector in the LINDA Germany BAU, EFF and IND scenarios.

The CO_2 emissions (Figure 26) follow the path of the use of fossil fuels in the different LINDA Germany scenarios. The emissions drop almost to zero in the EFF scenario, but they remain quite large in the IND scenario.

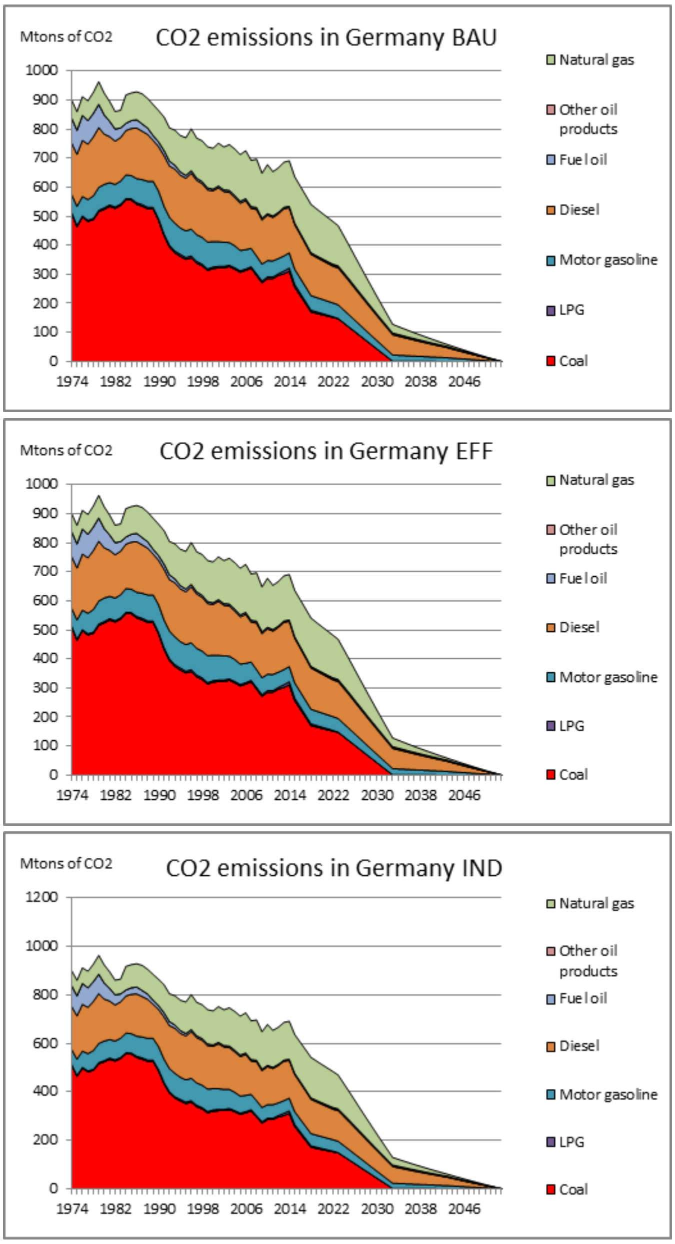

Figure 26. CO_2 emissions from fossil fuel combustion in the LINDA Germany BAU, EFF and IND scenarios.

Electricity production in different scenarios is illustrated in Figure 27. Nuclear power will be phased out following the political decision in Germany, and it will be replaced mainly by wind and solar in all scenarios following the “Energiewende”.

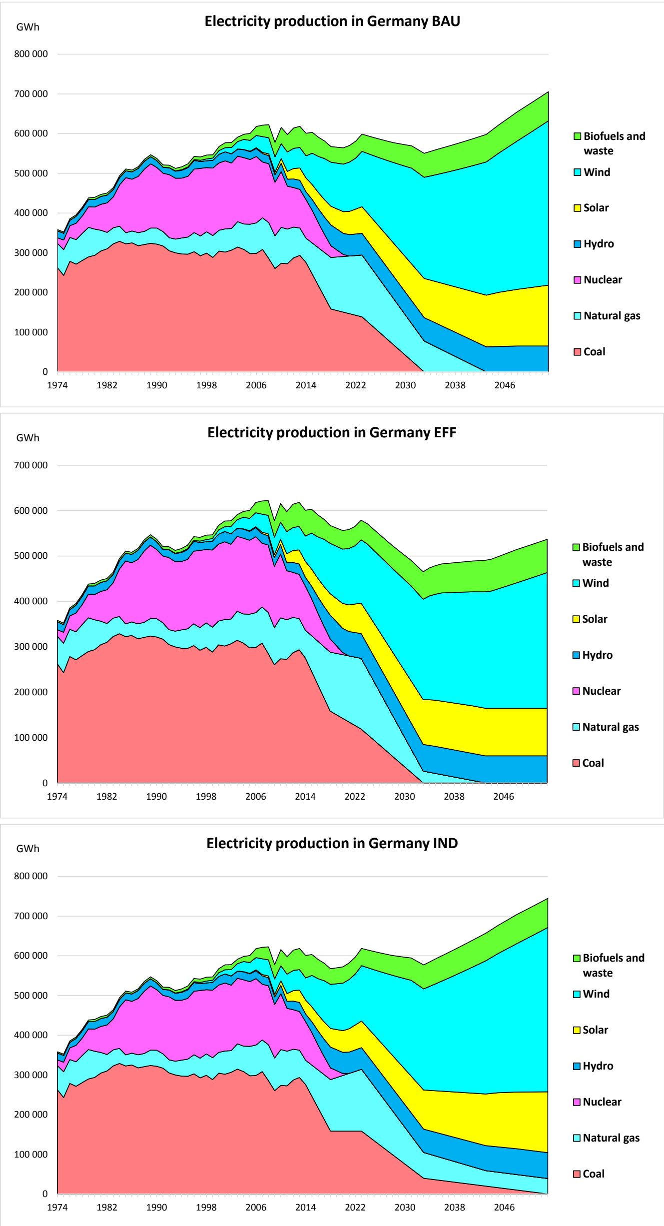

Figure 27. Electricity production in the LINDA Germany BAU, EFF and IND scenarios.

Electricity production is planned so that the needed electricity import (import = demand – production) is similar in all scenarios in order to make them comparable to each other (Figure 28). The peak of electricity imports after the year 2030 is the highest in the EFF scenario where the amount of electricity production is the smallest.

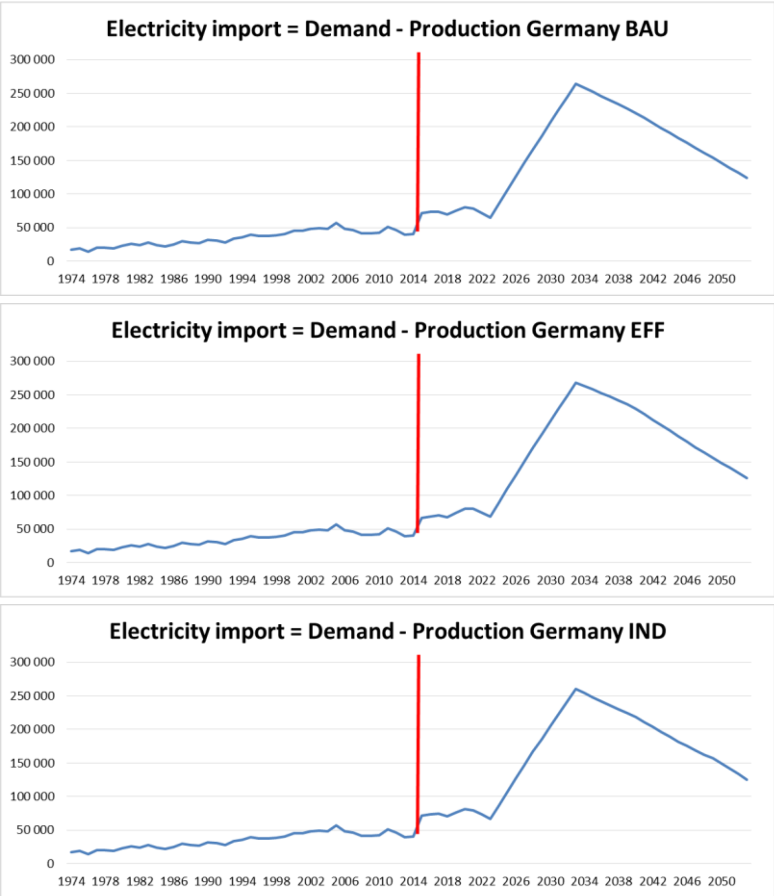

Figure 28. Electricity imports in the LINDA Germany BAU, EFF and IND scenarios.

Electricity production in the scenarios is quite different in Germany as seen in Figure 27 above. The new power plant capacity is mainly solar and wind capacity in all scenarios (Figure 29). The amount of new capacity is similar in BAU and IND scenarios. In the EFF scenario, need for new power plant capacity is smaller due to the lower electricity demand (Figure 30).

In all the scenarios, nuclear power production is assumed to be phased out until the year 2020 according to the political decisions in Germany. In the BAU scenario, electricity production from fossil energy sources (coal and gas) is assumed to be stopped by the early 2040's. In the EFF scenario, fossil fuel based electricity production can be reduced compared to the BAU scenario because of lower electricity demand, even though the amount of installed solar and wind capacity is much lower (Figure 30). In the EFF scenario, the investment costs of electricity production are the lowest. In the IND scenario, electricity consumption is so high that natural gas is still needed in electricity production in 2050. (Figure 27.)

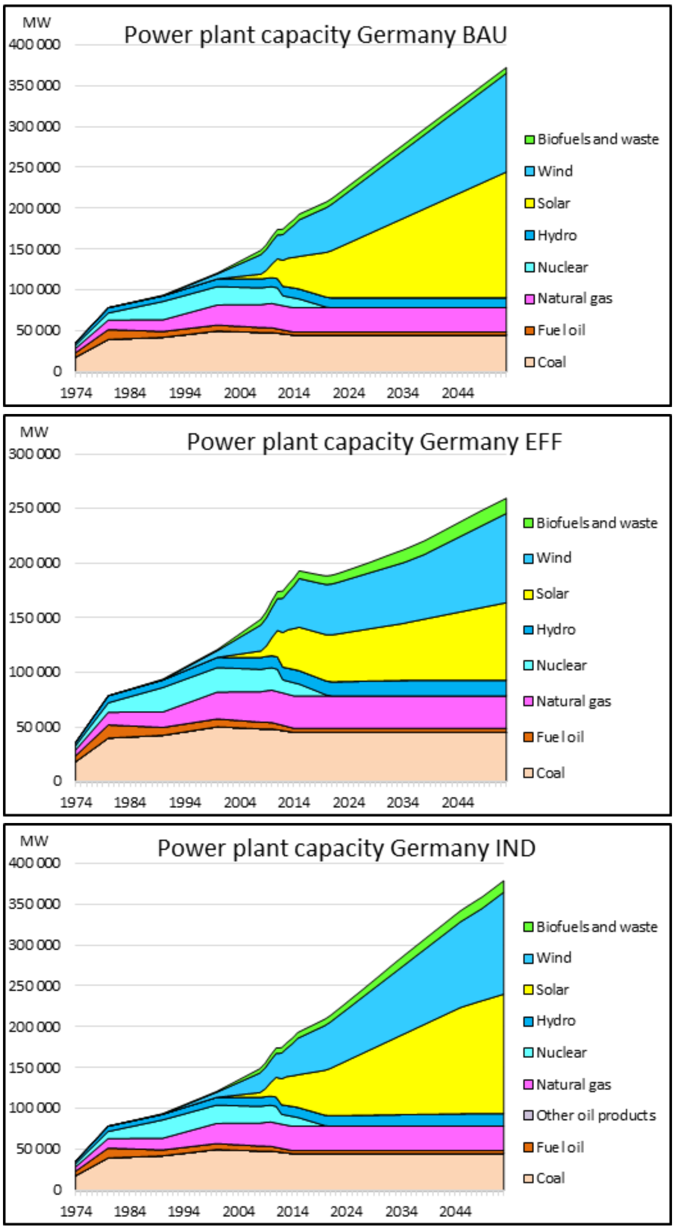

Figure 29. Power plant capacity in the LINDA Germany BAU, EFF and IND scenarios.

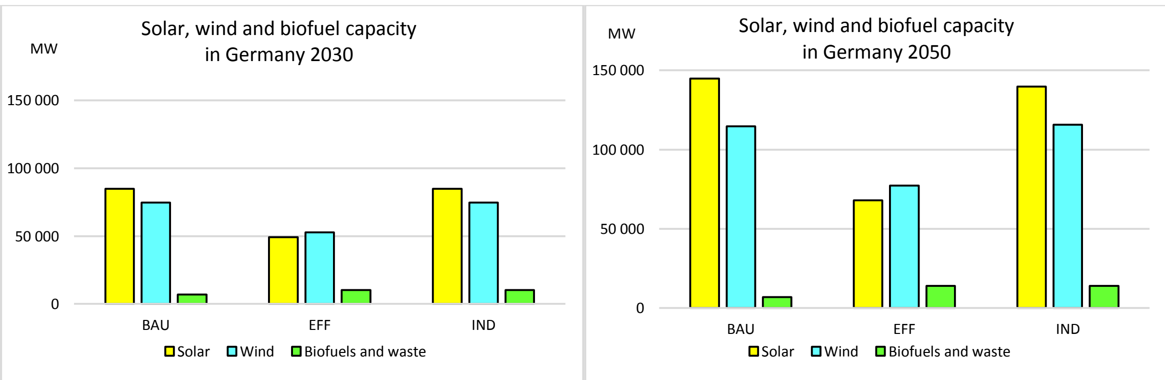

Figure 30. Solar, wind and biofuel capacities in LINDA Germany BAU, EFF and IND scenarios.

Primary energy intensity and final energy intensity are decreasing in all LINDA Germany scenarios (Figure 31). Both intensities reach their lowest value in the EFF scenario, where energy use is the lowest. Figure 31 shows also the development of efficiency of the entire energy transformation system (indicator TPES/FEC). Historically, there has been no clear trend as also reported in EUFORIE deliverable D2.1, but the TPES/FEC ratio improves significantly during the assumed nuclear phase-out and simultaneous investments in additional capacity of wind and solar power[2]. Later, the ratio increases again when FEC starts to decrease at a faster rate than TPES in all LINDA Germany scenarios.

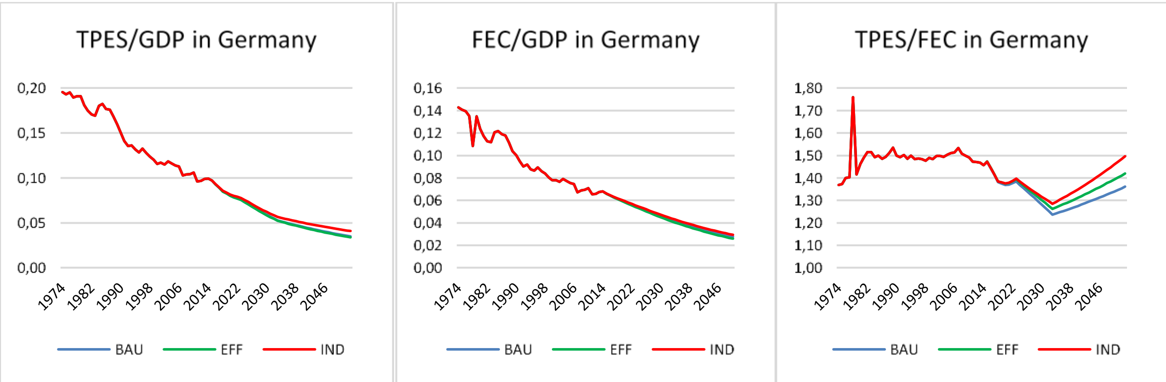

Figure 31. Primary energy intensity (TPES/GDP), final energy intensity (FEC/GDP) and TPES/GDP ratio in the LINDA Germany BAU, EFF and IND scenarios.

Improvement of energy efficiency in different scenarios, measured as a reduction in primary energy intensity (TPES/GDP), is shown in Figure 32. The reduction of the energy intensity until the year 2030 is compared to the values of years 1990, 2005 and 2010. Because the historical energy intensity in Germany has been decreasing, and thus the largest efficiency improvements (61 % in the BAU and EFF scenarios, and 59 % in the IND scenario) can be seen when the year of comparison is 1990.

[2] Nuclear electricity is calculated in IEA and Eurostat energy statistics as primary energy with a coefficient 3, while the coefficient for wind and solar is 1. In other words, the change in the ratio TPES/FEC is not a result of any improvement in technical efficiency, or change in any technical coefficients.

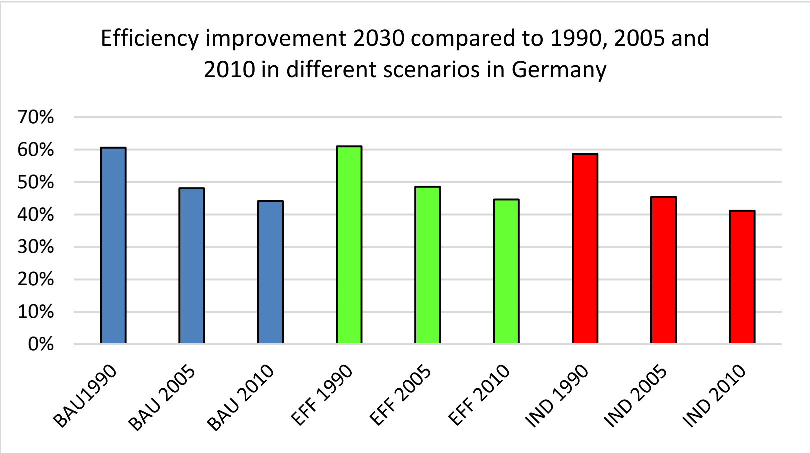

Figure 32. Improvements in energy efficiency in the LINDA Germany BAU, EFF and IND scenarios, primary energy intensity (TPES/GDP) in 2030 in comparison to energy efficiency in 1990, 2005 and 2010.

Italy

Scenario "LINDA Italy BAU" (Table 26) is a baseline scenario, where past trends of economic development and electricity intensity continue. The fuel intensity changes are assumed to be similar to the BAU scenario in all other scenarios. Tables 26-28 show the assumptions for economic development and the assumed changes in electricity and fuel efficiencies for the LINDA BAU, EFF and IND scenarios for Italy.

Scenario "LINDA Italy EFF" (Table 27) is an energy efficiency scenario, which has similar economic growth figures for all sectors (agriculture and forestry, industry, transportation and communication, and commercial) to the BAU scenario. In the EFF scenario, electricity efficiency in the industrial and commercial sectors is assumed to improve faster than in the BAU scenario. In transport and communications sector, electricity intensity of the EFF scenario is the same as in the BAU scenario. In this sector, electricity intensity is assumed to increase in the future with a shift to more electrical vehicles.

Scenario "LINDA Italy IND" (Table 28) is an industrial scenario with higher growth figures for industrial sector and lower growth rate for commercial sector than in the BAU and EFF scenarios. This means that the IND scenario assumes a structural change taking place in the economy, towards more industrial development. The electricity intensity figures in the IND scenario are similar to the BAU scenario, so this scenario is analyzing the impact of structural change in the economy, and the possible restrictions caused by it.

Table 26. Assumptions of the LINDA Italy BAU scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Italy BAU			Scenario start year	2013	(2005-2026)		
Start years of periods	1972	1991	2001	2009	2013	2016	2021	2026	2031	2041
End years of periods	1990	2000	2008	2012	2015	2020	2025	2030	2040	2051
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
GDP	1972-1990	1991-2000	2001-2008	2009-2012	2013-2015	2016-2020	2021-2025	2026-2030	2031-2040	2041-2051
Agriculture and forestry	1.7 %	1.7 %	-0.1 %	-0.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Industry	2.9 %	1.0 %	0.8 %	0.1 %	1.0 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Transportation, communication	4.7 %	4.7 %	2.6 %	0.2 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.1 %	1.5 %	0.6 %	0.2 %	1.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Total	3.1 %	1.5 %	0.8 %	0.2 %	1.1 %	1.6 %	1.6 %	1.7 %	1.7 %	1.7 %
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
Electricity intensity ktoe/million USD	1972-1990	1991-2000	2001-2008	2009-2012	2013-2015	2016-2020	2021-2025	2026-2030	2031-2040	2041-2051
Agriculture and forestry, electricity intensity	5.6 %	0.0 %	1.5 %	1.8 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	0.0 %	0.0 %
Industry, electricity intensity	-0.4 %	1.7 %	-1.0 %	-0.2 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %
Transportation and communication, electricity intensity	-1.4 %	-2.5 %	0.8 %	0.4 %	1.0 %	1.0 %	1.0 %	1.0 %	2.0 %	2.0 %
Commercial, electricity intensity	3.1 %	1.7 %	4.3 %	2.1 %	2.0 %	1.0 %	0.5 %	0.2 %	0.0 %	-0.5 %
Residential electricity use (not intensity)	4.4 %	1.2 %	1.5 %	0.3 %	2.0 %	2.0 %	2.0 %	2.0 %	1.0 %	1.0 %
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
Energy (fuel use) intensity changes ktoe/mill.	1972-1990	1991-2000	2001-2008	2009-2012	2013-2015	2016-2020	2021-2025	2026-2030	2031-2040	2041-2051
Agriculture and forestry, fuel intensity	0.7 %	-1.2 %	-1.2 %	-3.7 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-4.0 %	0.1 %	-4.2 %	-0.9 %	0.0 %	-0.5 %	-0.5 %	-1.0 %	-1.0 %	-1.0 %
Transportation and communication, fuel intensity	-1.2 %	-2.7 %	-2.4 %	-2.7 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-3.0 %	-4.0 %
Commercial, fuel intensity	12.9 %	0.7 %	4.6 %	-5.8 %	-1.0 %	-1.0 %	-2.0 %	-2.0 %	-2.5 %	-3.0 %
Residential use (not intensity)	-0.5 %	-0.6 %	-1.4 %	6.6 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

Table 27. Assumptions of the LINDA Italy EFF scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Italy EFF			Scenario start year	2013	(2005-2026)		
Start years of periods	1972	1991	2001	2009	2013	2016	2021	2026	2031	2041
End years of periods	1990	2000	2008	2012	2015	2020	2025	2030	2040	2051
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
GDP	1972-1990	1991-2000	2001-2008	2009-2012	2013-2015	2016-2020	2021-2025	2026-2030	2031-2040	2041-2051
Agriculture and forestry	1.7 %	1.7 %	-0.1 %	-0.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Industry	2.9 %	1.0 %	0.8 %	0.1 %	1.0 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Transportation, communication	4.7 %	4.7 %	2.6 %	0.2 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.1 %	1.5 %	0.6 %	0.2 %	1.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Total	3.1 %	1.5 %	0.8 %	0.2 %	1.1 %	1.6 %	1.6 %	1.7 %	1.7 %	1.7 %
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
Electricity intensity ktoe/million USD	1972-1990	1991-2000	2001-2008	2009-2012	2013-2015	2016-2020	2021-2025	2026-2030	2031-2040	2041-2051
Agriculture and forestry, electricity intensity	5.6 %	0.0 %	1.5 %	1.8 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	0.0 %	0.0 %
Industry, electricity intensity	-0.4 %	1.7 %	-1.0 %	-0.2 %	-1.0 %	-1.5 %	-1.5 %	-1.5 %	-1.5 %	-1.5 %
Transportation and communication, electricity intensity	-1.4 %	-2.5 %	0.8 %	0.4 %	1.0 %	1.0 %	1.0 %	1.0 %	2.0 %	2.0 %
Commercial, electricity intensity	3.1 %	1.7 %	4.3 %	2.1 %	1.0 %	0.5 %	0.0 %	-0.3 %	-0.8 %	-1.0 %
Residential electricity use (not intensity)	4.4 %	1.2 %	1.5 %	0.3 %	2.0 %	2.0 %	2.0 %	2.0 %	1.0 %	1.0 %
Annual percentual changes	Fill in the future annual growth rates (%) in the yellow cells									
Energy (fuel use) intensity changes ktoe/mill.	1972-1990	1991-2000	2001-2008	2009-2012	2013-2015	2016-2020	2021-2025	2026-2030	2031-2040	2041-2051
Agriculture and forestry, fuel intensity	0.7 %	-1.2 %	-1.2 %	-3.7 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-4.0 %	0.1 %	-4.2 %	-0.9 %	0.0 %	-0.5 %	-0.5 %	-1.0 %	-1.0 %	-1.0 %
Transportation and communication, fuel intensity	-1.2 %	-2.7 %	-2.4 %	-2.7 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-3.0 %	-4.0 %
Commercial, fuel intensity	12.9 %	0.7 %	4.6 %	-5.8 %	-1.0 %	-1.0 %	-2.0 %	-2.0 %	-2.5 %	-3.0 %
Residential use (not intensity)	-0.5 %	-0.6 %	-1.4 %	6.6 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

Table 28. Assumptions of the LINDA Italy IND scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Italy IND		Scenario start year		2013	(2005-2026)		
Start years of periods	1972	1991	2001	2009	2013	2016	2021	2026	2031	2041
End years of periods	1990	2000	2008	2012	2015	2020	2025	2030	2040	2051
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
GDP	**1972-1990**	**1991-2000**	**2001-2008**	**2009-2012**	**2013-2015**	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2051**
Agriculture and forestry	1.7 %	1.7 %	-0.1 %	-0.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Industry	2.9 %	1.0 %	0.8 %	0.1 %	1.0 %	1.5 %	2.0 %	3.0 %	3.0 %	3.0 %
Transportation, communication	4.7 %	4.7 %	2.6 %	0.2 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.1 %	1.5 %	0.6 %	0.2 %	1.0 %	0.5 %	0.5 %	0.5 %	0.2 %	0.0 %
Total	3.1 %	1.5 %	0.8 %	0.2 %	1.1 %	0.9 %	1.0 %	1.3 %	1.2 %	1.3 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Electricity intensity ktoe/million USD	**1972-1990**	**1991-2000**	**2001-2008**	**2009-2012**	**2013-2015**	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2051**
Agriculture and forestry, electricity intensity	5.6 %	0.0 %	1.5 %	1.8 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	0.0 %	0.0 %
Industry, electricity intensity	-0.4 %	1.7 %	-1.0 %	-0.2 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %
Transportation and communication, electricity intensity	-1.4 %	-2.5 %	0.8 %	0.4 %	1.0 %	1.0 %	1.0 %	1.0 %	2.0 %	2.0 %
Commercial, electricity intensity	3.1 %	1.7 %	4.3 %	2.1 %	2.0 %	1.0 %	0.5 %	0.2 %	0.0 %	-0.5 %
Residential electricity use (not intensity)	4.4 %	1.2 %	1.5 %	0.3 %	2.0 %	2.0 %	2.0 %	2.0 %	1.0 %	1.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Energy (fuel use) intensity changes ktoe/mill.	**1972-1990**	**1991-2000**	**2001-2008**	**2009-2012**	**2013-2015**	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2051**
Agriculture and forestry, fuel intensity	0.7 %	-1.2 %	-1.2 %	-3.7 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-4.0 %	0.1 %	-4.2 %	-0.9 %	0.0 %	-0.5 %	-0.5 %	-1.0 %	-1.0 %	-1.0 %
Transportation and communication, fuel intensity	-1.2 %	-2.7 %	-2.4 %	-2.7 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-3.0 %	-4.0 %
Commercial, fuel intensity	12.9 %	0.7 %	4.6 %	-5.8 %	-1.0 %	-1.0 %	-2.0 %	-2.0 %	-2.5 %	-3.0 %
Residential use (not intensity)	-0.5 %	-0.6 %	-1.4 %	6.6 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

The economic development of the LINDA Italy scenarios is shown in Figure 33. The BAU and EFF scenarios have similar development, but in the IND scenario the industrial sector grows fast. The total growth of GDP is, however, same in all the scenarios in order to make them comparable to each other.

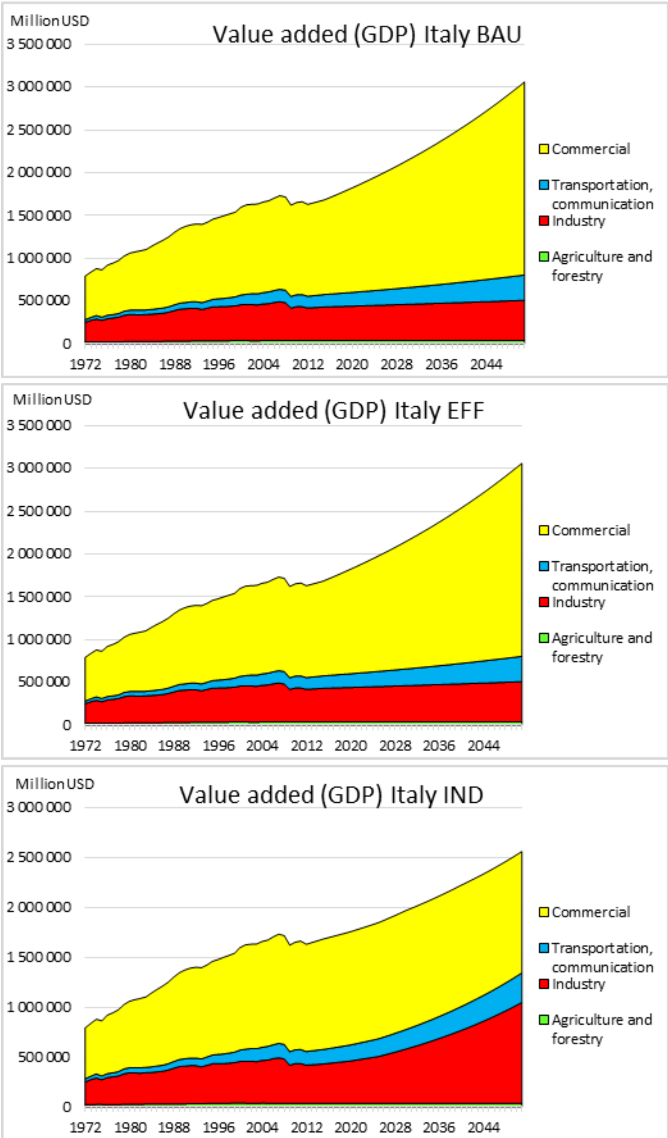

Figure 33. Assumed economic growth in different sectors in the LINDA Italy BAU, EFF and IND scenarios.

The electricity consumption varies considerably in the different LINDA Italy scenarios (Figure 34). The consumption continues to grow in the BAU scenario in all the sectors except industry, mainly due to the assumed fast economic growth. In the EFF scenario, growth of electricity consumption is much smaller than in other scenarios due to improved electricity efficiency in the industrial and commercial sectors. In addition, growth in household sector is assumed to slow down because of introduction of new electricity saving appliances. In the IND scenario, electricity consumption continues to grow considerably due to fast economic growth in the industrial sector, where electricity intensity in high. Even though the total economic growth is the same as in the BAU scenario, the electricity demand will be much larger. (Figure 34.)

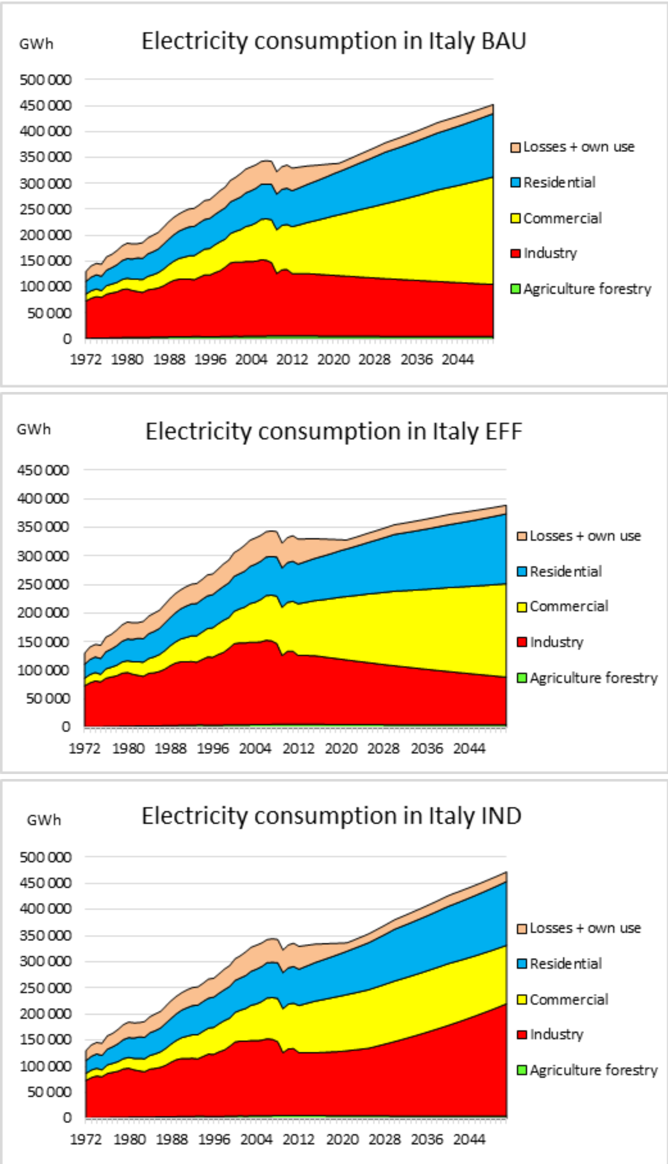

Figure 34. Electricity consumption in different sectors in the LINDA Italy BAU, EFF and IND scenarios.

The sectoral final energy use is shown in Figure 35. There is not as large difference between the scenarios as in electricity consumption because the fuel intensities in different scenarios were assumed to improve in the same way.

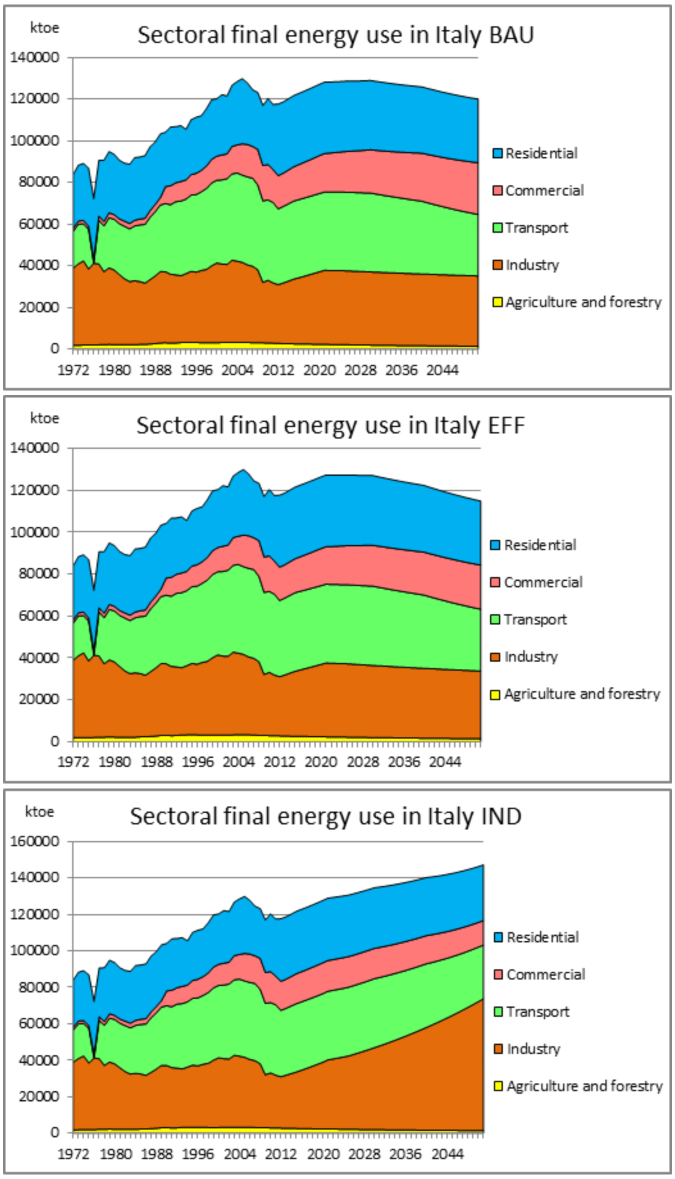

Figure 35. Final energy consumption in different sectors in the LINDA Italy BAU, EFF and IND scenarios.

Fuel use in different scenarios is shown in Figure 36. The sectoral fuel use shares in different sectors were assumed to be similar. The main difference comes from fuel use in power generation. All scenarios assume that the share of biofuels is increasing considerably due to climate policy measures. This means that the fossil fuels are in many cases assumed to be replaced by biofuels (e.g. biodiesel).

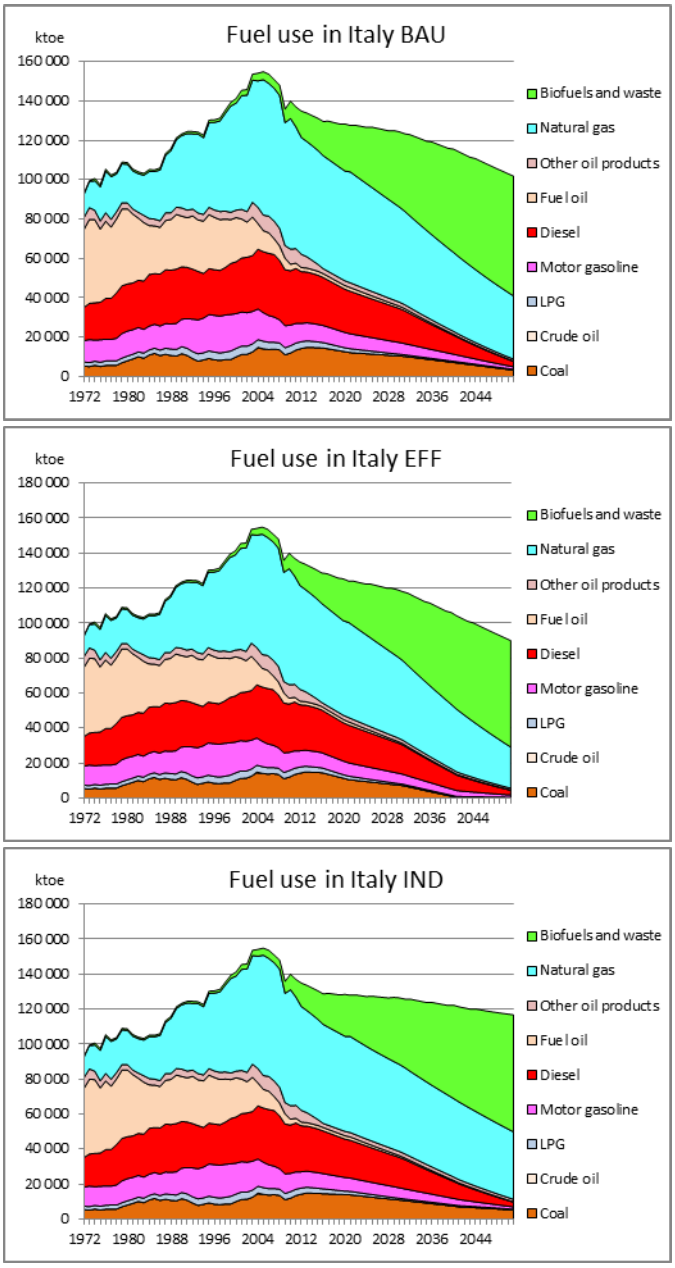

Figure 36. Use of fuels in the LINDA Italy BAU, EFF and IND scenarios.

The industrial energy use is shown in Figure 37. In the EFF scenario, industrial electricity use is smaller than in BAU scenario because of improved efficiency. In the IND scenario, industrial energy use increases considerably due to the fast growth of industrial output.

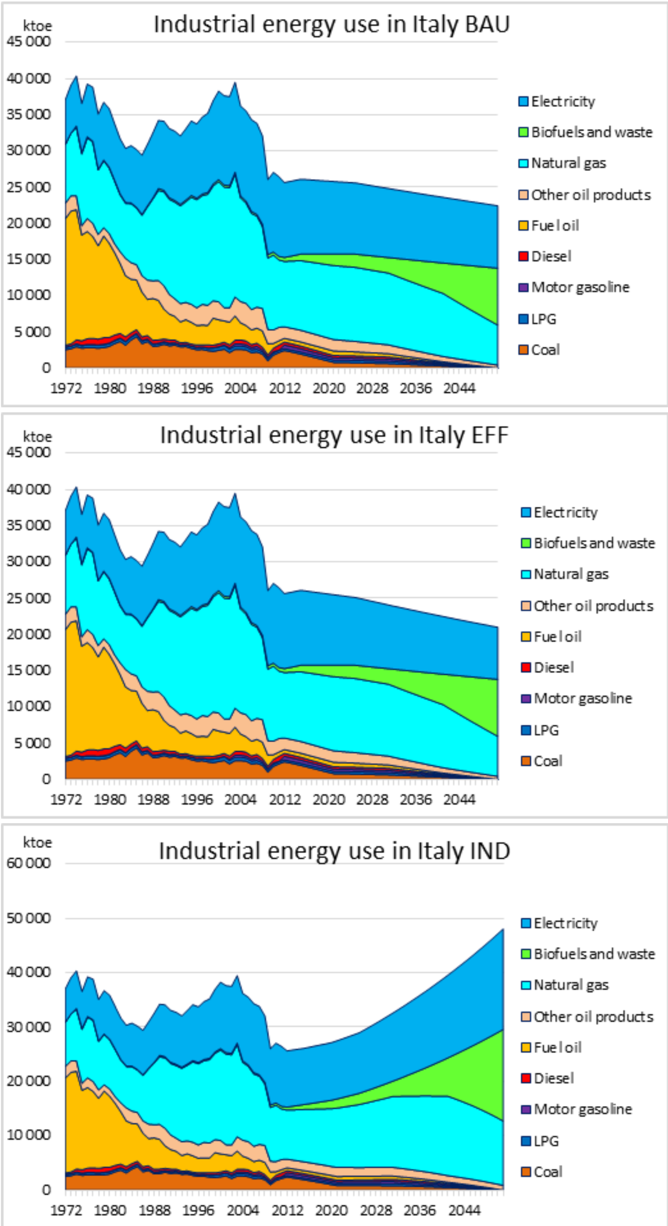

Figure 37. Industrial energy use in the LINDA Italy BAU, EFF and IND scenarios.

Energy use in commercial sector in the LINDA Italy scenarios is shown in Figure 38. In the IND scenario, energy use in commercial sector is the smallest because economic growth in this sector is assumed to be smaller than in the other scenarios. In the EFF scenario, energy use in commercial sector grows more slowly than in the BAU scenario, because efficiency improvements partly cancel the impacts of economic growth. In the commercial sector, energy consumption is mainly electricity consumption.

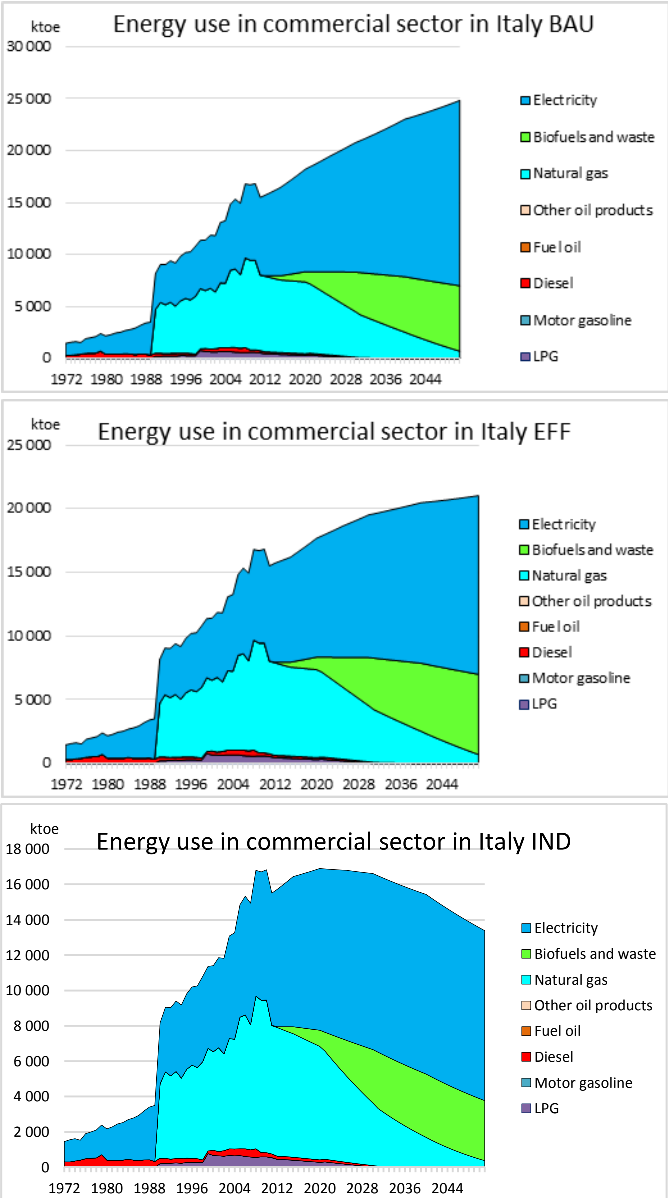

Figure 38. Energy use in the commercial sector in the LINDA Italy BAU, EFF and IND scenarios.

The residential energy use is assumed to be similar in all LINDA Italy scenarios (Figure 39).

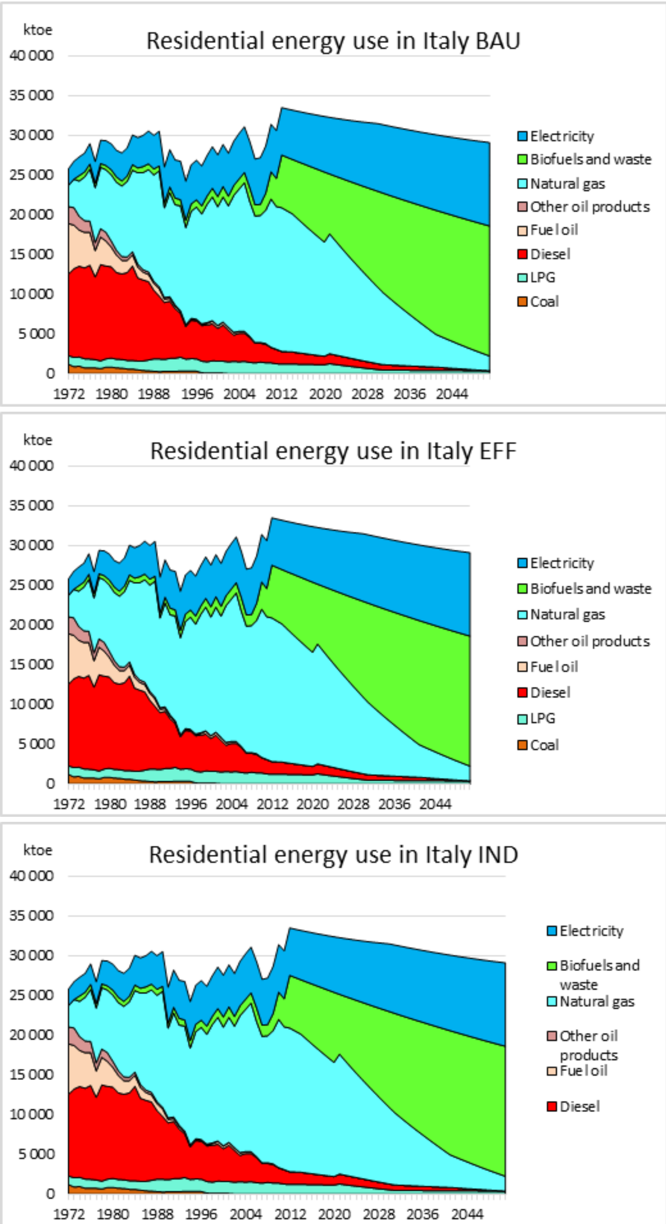

Figure 39. Residential energy use in the LINDA Italy BAU, EFF and IND scenarios.

The CO_2 emissions in the different LINDA Italy scenarios follow the path of fossil fuel use (Figure 40). The emissions drop almost to zero in the EFF scenario, but they remain quite large in the IND scenario.

The fossil fuel use is assumed to decrease in all scenarios, as a result of climate policy measures and reduction of price of alternative electricity production (mainly solar and wind). In all scenarios, the amount of solar and wind power investments are assumed to be similar.

The reduction of fossil fuel use is the fastest in the EFF scenario. Electricity demand is lower than in other scenarios, and the carbon-free production can fulfil large share of the needed production. In the BAU scenario, investments in carbon-free production are not large enough to reduce fossil energy use to zero, and natural gas and coal remain as important power sources. In the IND scenario, electricity consumption is so large that carbon-free sources can produce sonly a part of the needed electricity, and more coal and natural gas (in the existing plants) is needed for power production (see Figure 42 below).

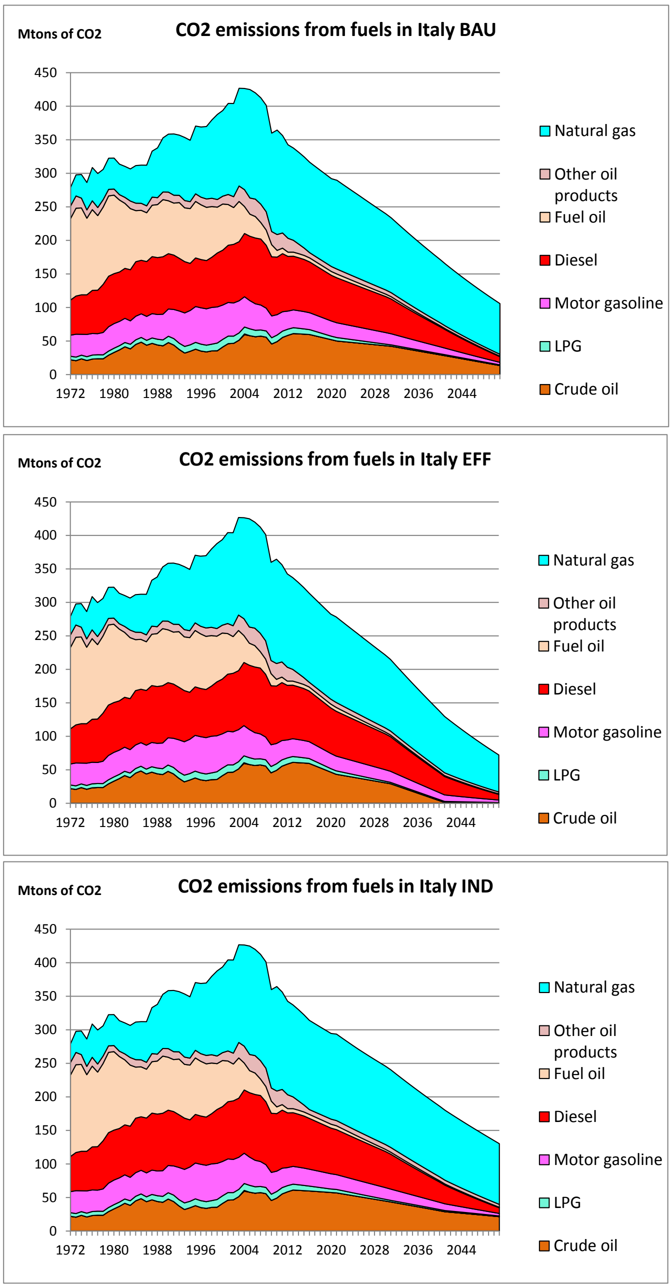

Figure 40. CO_2 emissions from fossil fuel combustion in the LINDA Italy BAU, EFF and IND scenarios.

In the different scenarios the electricity production is planned so that the needed import of electricity (Import = Demand – Production) is similar in order to make the scenarios comparable (Figure 41). This is achieved by changing the power plant capacity factors in the fossil fuel power plants. The installed power plant capacities are similar in all the scenarios.

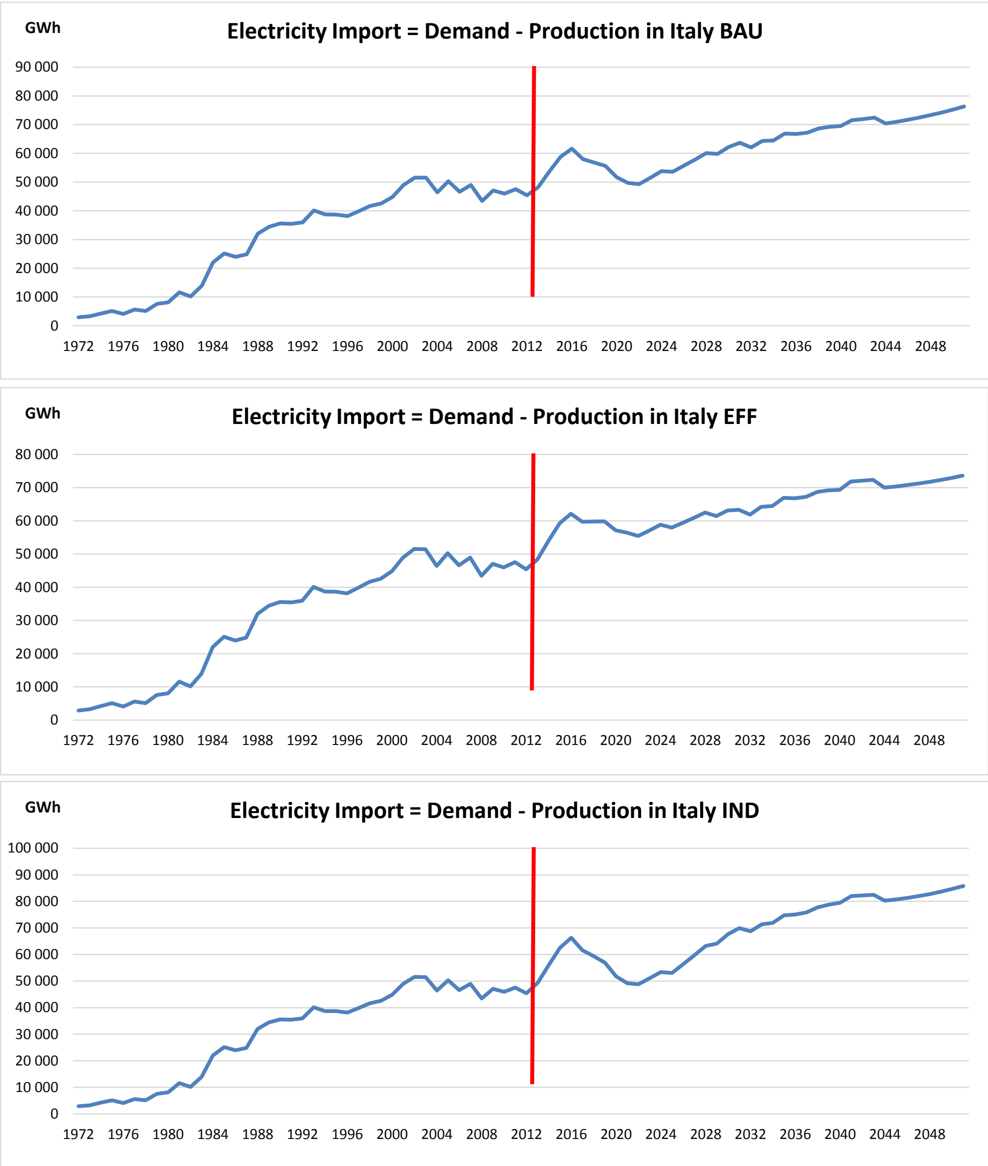

Figure 41. Electricity imports in the LINDA Italy BAU, EFF and IND scenarios.

The installed power plant capacity will increase only for solar and wind power, but the capacity factor of fossil fuel power plants is adjusted to have similar amount of imported electricity in all the LINDA Italy scenarios (Figure 42).

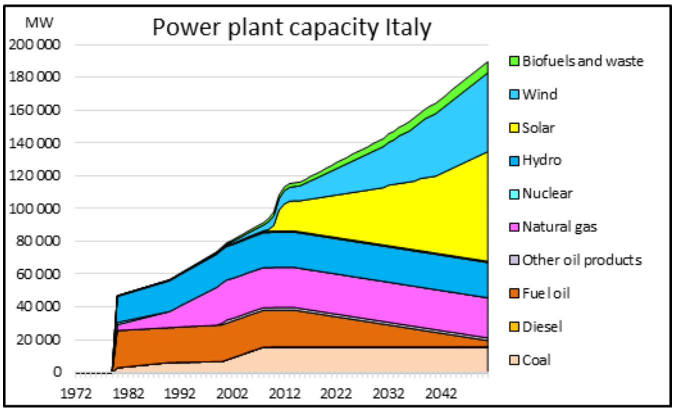

Figure 42. Power plant capacity in the LINDA Italy scenarios.

The development of energy intensities in different LINDA Italy scenarios is shown in Figure 43. Primary energy intensity (TPES/GDP) and final energy intensity (FEC/GDP) are decreasing in all scenarios, and the TPES/FEC ratio does the same. All indicators reach their lowest values in the EFF scenario, where energy demand is the smallest. The BAU and IND scenarios are identical in terms of the intensity indicators, so in Figure 43 the BAU scenario curves are hidden behind the IND scenario curves.

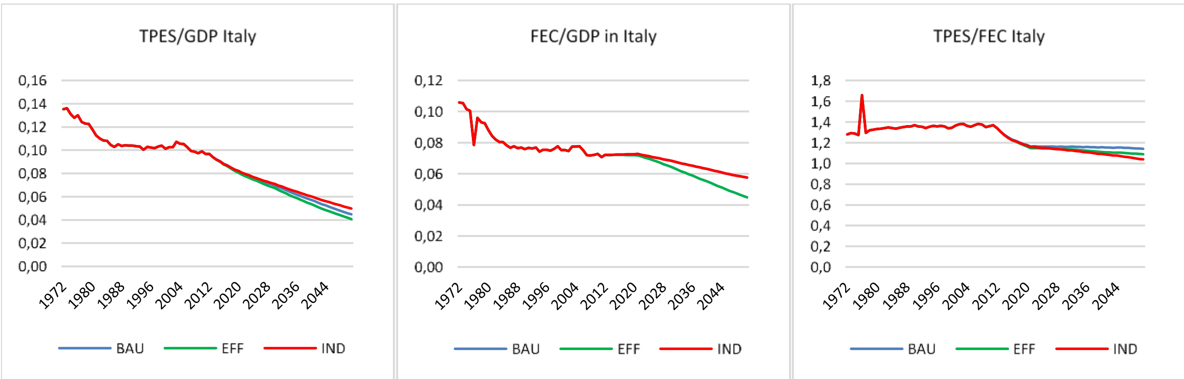

Figure 43. Primary energy intensity (TPES/FEC), final energy intensity (FEC/GDP), and the ratio of TPES/FEC in the LINDA Italy BAU, EFF and IND scenarios.

The energy efficiency improvement in different scenarios, measured as a reduction of primary energy intensity, is shown in Figure 44. The reduction of the energy intensity until the year 2030 is compared to the years 1990, 2005 and 2010 in the figures. Because primary energy intensity in Italy started a constant reduction after 2004, the largest efficiency improvements can be seen when the 2030 intensity is compared to the year 2005 value. In the BAU scenario, the efficiency improvement compared to 2005 is about 26 %, in EFF scenario about 30 % and in IND scenario about 27 %.

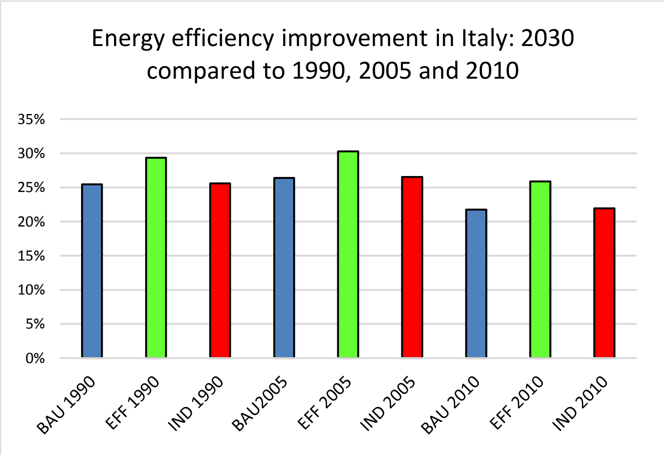

Figure 44. Improvements in energy efficiency in the LINDA Italy BAU, EFF and IND scenarios, primary energy intensity (TPES/GDP) in 2030 in the LINDA Italy scenarios is compared to the 1990, 2005 and 2010 values of TPES/GDP.

Spain

Scenario "LINDA Spain BAU" (Table 29) is a baseline scenario, where past trends of economic development and electricity intensity will continue in the different sectors of the Spanish national economy. The fuel intensity changes are assumed to be similar to the BAU scenario also in all other scenarios. Tables 29-30 show the basic assumptions for economic development and the assumed changes in electricity and fuel efficiencies for different sectors in the LINDA Spain BAU, EFF and IND scenarios.

Scenario "LINDA Spain EFF" (Table 30) is an energy efficiency scenario, which has similar economic growth figures for all sectors (agriculture and forestry, industry, transportation and communication, and commercial) to the BAU scenario. In the EFF scenario, electricity efficiency in the industrial and commercial sectors is assumed to improve faster than in the BAU scenario. In transport and communications sector, electricity intensity of the EFF scenario is the same as in the BAU scenario. In this sector, electricity intensity is assumed to increase in the future with a shift to electric vehicles.

Scenario "LINDA Spain IND" (Table 31) is an industrial scenario with a high economic growth rate for the industrial sector, and lower growth rate for commercial sector than in the BAU and EFF scenarios. This means that the IND scenario assumes that a structural change takes place in the economy towards more industrial development. Electricity intensity figures in the IND scenario are similar to the BAU scenario, so this scenario is analyzing the impact of structural change and the possible restrictions caused by it.

Table 29. Assumptions of the LINDA Spain BAU scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Spain BAU			Scenario start year	2015	(2005-2026)		
Start years of periods	1974	1991	2001	2009	2015	2017	2021	2026	2031	2041
End years of periods	1990	2000	2008	2014	2016	2020	2025	2030	2040	2053
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
GDP	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry	2.0 %	3.1 %	-0.1 %	0.6 %	0.0 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Industry	1.5 %	2.0 %	1.6 %	-5.0 %	1.0 %	1.0 %	1.5 %	1.5 %	1.3 %	1.3 %
Transportation, communication	2.2 %	2.7 %	2.3 %	1.7 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.3 %	2.4 %	4.2 %	0.1 %	2.5 %	2.4 %	2.2 %	2.2 %	2.2 %	2.2 %
Total	2.5 %	2.3 %	3.1 %	-1.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Electricity intensity ktoe/million USD	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, electricity intensity	4.0 %	0.6 %	1.6 %	-7.7 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, electricity intensity	1.0 %	1.1 %	-1.0 %	2.9 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %
Transportation and communication, electricity intensity	3.5 %	-1.5 %	-7.5 %	5.0 %	1.0 %	0.0 %	-1.0 %	-1.0 %	0.0 %	1.0 %
Commercial, electricity intensity	4.1 %	5.2 %	2.2 %	-1.4 %	-1.0 %	-1.0 %	-1.4 %	-1.4 %	-1.4 %	-1.4 %
Residential electricity use (not intensity)	6.3 %	3.9 %	4.9 %	-0.1 %	2.0 %	2.0 %	1.5 %	1.3 %	1.2 %	1.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Energy (fuel use) intensity changes ktoe/mill.	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	-1.5 %	13.0 %	15.7 %	38.2 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-2.5 %	-0.8 %	-2.7 %	8.3 %	0.0 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Transportation and communication, fuel intensity	1.5 %	0.8 %	0.0 %	-7.3 %	-1.0 %	-2.0 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %
Commercial, fuel intensity	-4.5 %	1.8 %	-4.7 %	5.0 %	0.0 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Residential use (not intensity)	3.9 %	0.9 %	2.8 %	-1.6 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

Table 30. Assumptions of the LINDA Spain EFF scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Spain EFF			Scenario start year	2015	(2005-2026)		
Start years of periods	1974	1991	2001	2009	2015	2017	2021	2026	2031	2041
End years of periods	1990	2000	2008	2014	2016	2020	2025	2030	2040	2053
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
GDP	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry	2.0 %	3.1 %	-0.1 %	0.6 %	0.0 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Industry	1.5 %	2.0 %	1.6 %	-5.0 %	1.0 %	1.0 %	1.5 %	1.5 %	1.3 %	1.3 %
Transportation, communication	2.2 %	2.7 %	2.3 %	1.7 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.3 %	2.4 %	4.2 %	0.1 %	2.5 %	2.4 %	2.2 %	2.2 %	2.2 %	2.2 %
Total	2.5 %	2.3 %	3.1 %	-1.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Electricity intensity ktoe/million USD	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, electricity intensity	4.0 %	0.6 %	1.6 %	-7.7 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, electricity intensity	1.0 %	1.1 %	-1.0 %	2.9 %	-1.5 %	-1.8 %	-2.0 %	-2.4 %	-2.4 %	-2.4 %
Transportation and communication, electricity intensity	3.5 %	-1.5 %	-7.5 %	5.0 %	1.0 %	0.0 %	-1.0 %	-1.0 %	0.0 %	1.0 %
Commercial, electricity intensity	4.1 %	5.2 %	2.2 %	-1.4 %	-2.0 %	-2.0 %	-2.2 %	-2.2 %	-2.4 %	-2.5 %
Residential electricity use (not intensity)	6.3 %	3.9 %	4.9 %	-0.1 %	1.0 %	1.0 %	1.0 %	0.9 %	0.8 %	0.6 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Energy (fuel use) intensity changes ktoe/mill.	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	-1.5 %	13.0 %	15.7 %	38.2 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-2.5 %	-0.8 %	-2.7 %	8.3 %	0.0 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Transportation and communication, fuel intensity	1.5 %	0.8 %	0.0 %	-7.3 %	-1.0 %	-2.0 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %
Commercial, fuel intensity	-4.5 %	1.8 %	-4.7 %	5.0 %	0.0 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Residential use (not intensity)	3.9 %	0.9 %	2.8 %	-1.6 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

Table 31. Assumptions of the LINDA Spain IND scenario on economic growth, electricity intensity and fuel intensity per economic sector.

Input for scenario calculation for		Country name	Spain IND		Scenario start year	2015	(2005-2026)			
Start years of periods	1974	1991	2001	2009	2015	2017	2021	2026	2031	2041
End years of periods	1990	2000	2008	2014	2016	2020	2025	2030	2040	2053
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
GDP	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry	2.0 %	3.1 %	-0.1 %	0.6 %	0.0 %	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Industry	1.5 %	2.0 %	1.6 %	-5.0 %	2.1 %	3.0 %	3.5 %	3.5 %	3.5 %	3.3 %
Transportation, communication	2.2 %	2.7 %	2.3 %	1.7 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Commercial	3.3 %	2.4 %	4.2 %	0.1 %	2.0 %	1.7 %	1.5 %	1.4 %	1.3 %	1.3 %
Total	2.5 %	2.3 %	3.1 %	-1.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %	2.0 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Electricity intensity ktoe/million USD	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, electricity intensity	4.0 %	0.6 %	1.6 %	-7.7 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, electricity intensity	1.0 %	1.1 %	-1.0 %	2.9 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %
Transportation and communication, electricity intensity	3.5 %	-1.5 %	-7.5 %	5.0 %	1.0 %	0.0 %	-1.0 %	-1.0 %	0.0 %	1.0 %
Commercial, electricity intensity	4.1 %	5.2 %	2.2 %	-1.4 %	-1.0 %	-1.0 %	-1.4 %	-1.4 %	-1.4 %	-1.4 %
Residential electricity use (not intensity)	6.3 %	3.9 %	4.9 %	-0.1 %	1.0 %	1.0 %	1.0 %	0.9 %	0.8 %	0.6 %
Annual percentual changes	*Fill in the future annual growth rates (%) in the yellow cells*									
Energy (fuel use) intensity changes ktoe/mill.	**1974-1990**	**1991-2000**	**2001-2008**	**2009-2014**	**2015-2016**	**2017-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2053**
Agriculture and forestry, fuel intensity	-1.5 %	13.0 %	15.7 %	38.2 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry, fuel intensity	-2.5 %	-0.8 %	-2.7 %	8.3 %	0.0 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Transportation and communication, fuel intensity	1.5 %	0.8 %	0.0 %	-7.3 %	-1.0 %	-2.0 %	-2.0 %	-3.0 %	-3.0 %	-3.0 %
Commercial, fuel intensity	-4.5 %	1.8 %	-4.7 %	5.0 %	0.0 %	-1.0 %	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Residential use (not intensity)	3.9 %	0.9 %	2.8 %	-1.6 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %	-1.0 %

The economic development in the LINDA Spain scenarios are shown in Figure 45. The BAU and EFF scenarios have a similar development, but the IND scenario has a fast growth of the industrial sector. The total GDP growth is, however, similar in all scenarios in order to make them more comparable to each other.

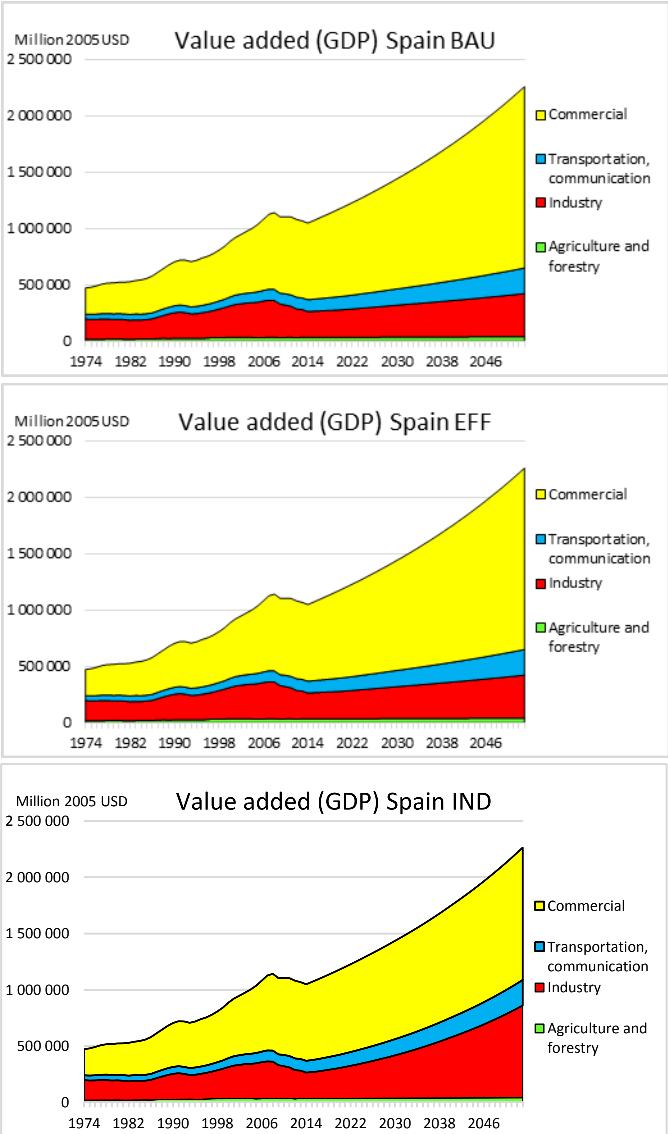

Figure 45. Assumed economic growth in the LINDA Spain BAU, EFF and IND scenarios.

Electricity consumption varies considerably in the different scenarios (Figure 46). In the BAU scenario, electricity consumption continues to grow in all sectors mainly due to assumed fast economic growth. In the EFF scenario, electricity consumption starts to decrease due to improved electricity efficiency in the industrial and commercial sectors. In the IND scenario, electricity consumption continues to grow considerably, due to fast economic growth in the industrial sector with a high electricity intensity. Even though total economic growth is the same as in the BAU scenario, electricity demand will be much higher in the IND scenario than in the BAU scenario.

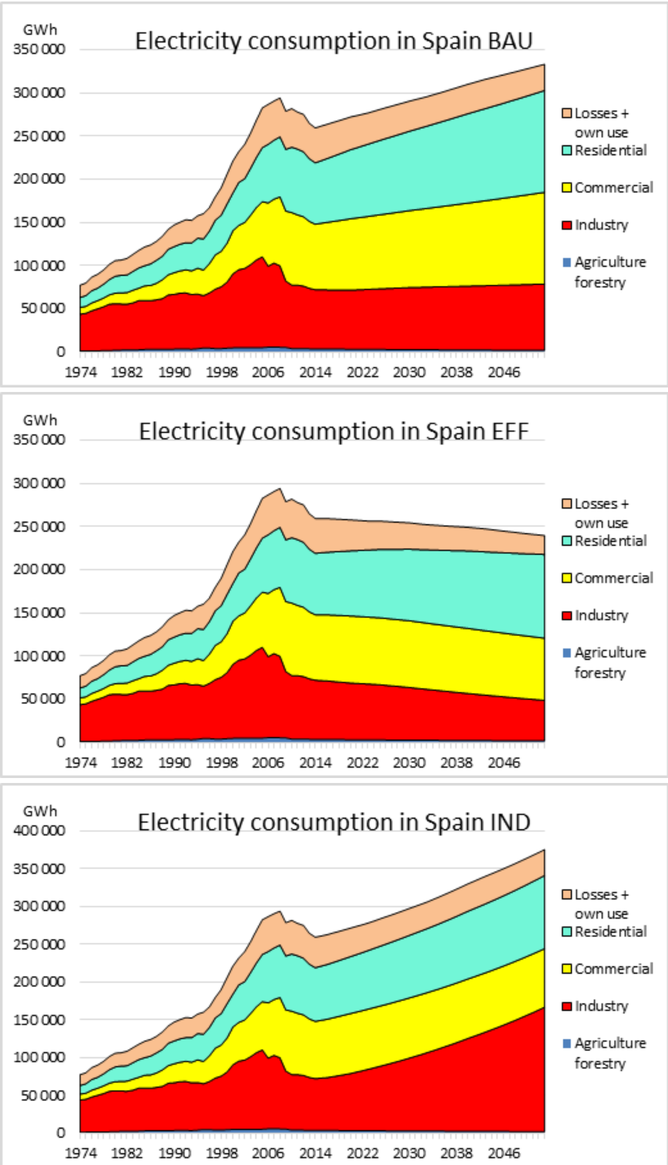

Figure 46. Electricity consumption in different sectors in the LINDA Spain BAU, EFF and IND scenarios.

The sectoral final energy use is shown in Figure 47. The difference between the scenarios is not as large as in the case of electricity consumption, because fuel intensities in different scenarios were assumed to change in the same way.

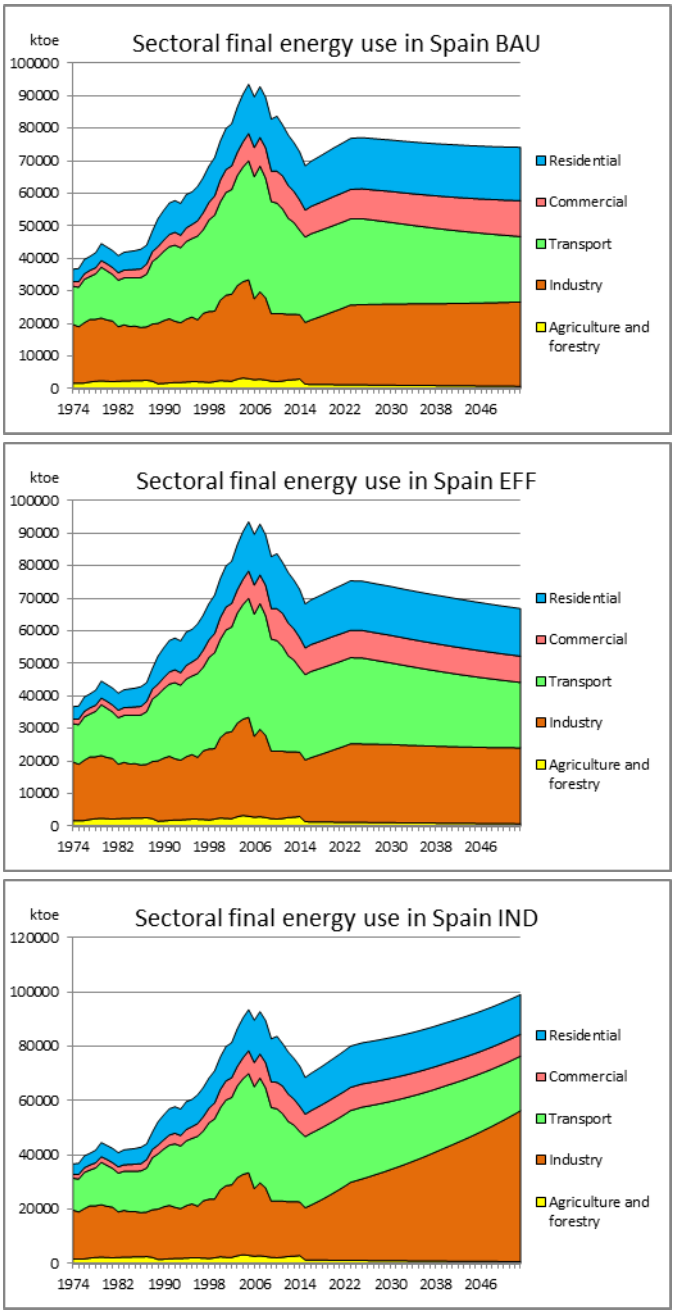

Figure 47. Final energy consumption by sector in the LINDA Spain BAU, EFF and IND scenarios.

Fuel use in different LINDA Spain scenarios is shown in Figure 48. The sectoral shares of fuel use were assumed to be similar in all scenarios. The main difference comes from the fuel use in power generation. In all scenarios, a considerable increase in the share of biofuels is assumed as a result of implementation of climate policy measures. This means that fossil fuels will be replaced by biofuels (e.g. biodiesel).

Reduction in the price of alternative electricity production technologies (mainly solar and wind) is also assumed. In all scenarios, the amount of investments in solar and wind power are assumed to be identical. The reduction in fossil fuel use is the fastest in the EFF scenario, because electricity demand is low and the carbon-neutral production can fulfil most of the energy demand by 2050. In the BAU scenario, investments in carbon-neutral production capacity are not large enough to replace all fossil fuels, and natural gas remains as an important power source. In the IND scenario, electricity demand is so large that carbon neutral sources cannot produce all the needed electricity. Coal and natural gas (in the existing plants) are still needed for power production in the IND scenario.

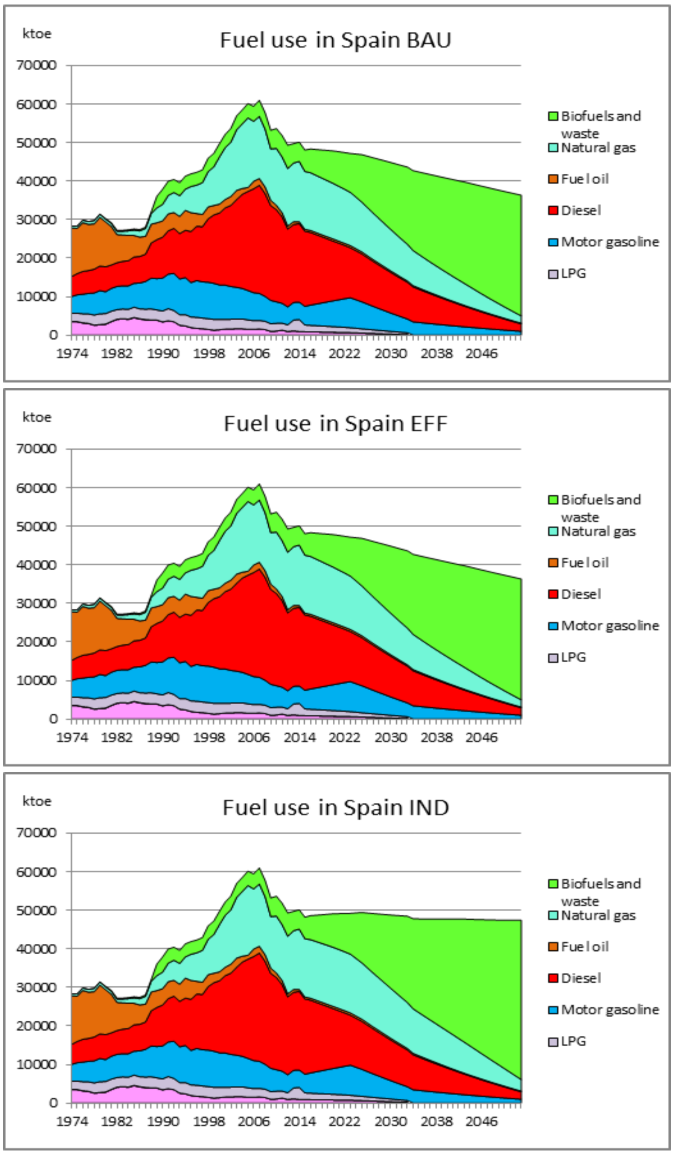

Figure 48. Total use of different fuels in the LINDA Spain BAU, EFF and IND scenarios.

The industrial energy use in different LINDA Spain scenarios is shown in Figure 49. In the EFF scenario, the industrial electricity use is smaller than in the BAU scenario, because of improved energy efficiency. In the IND scenario, the industrial energy use increases considerably due to fast growth of industrial output.

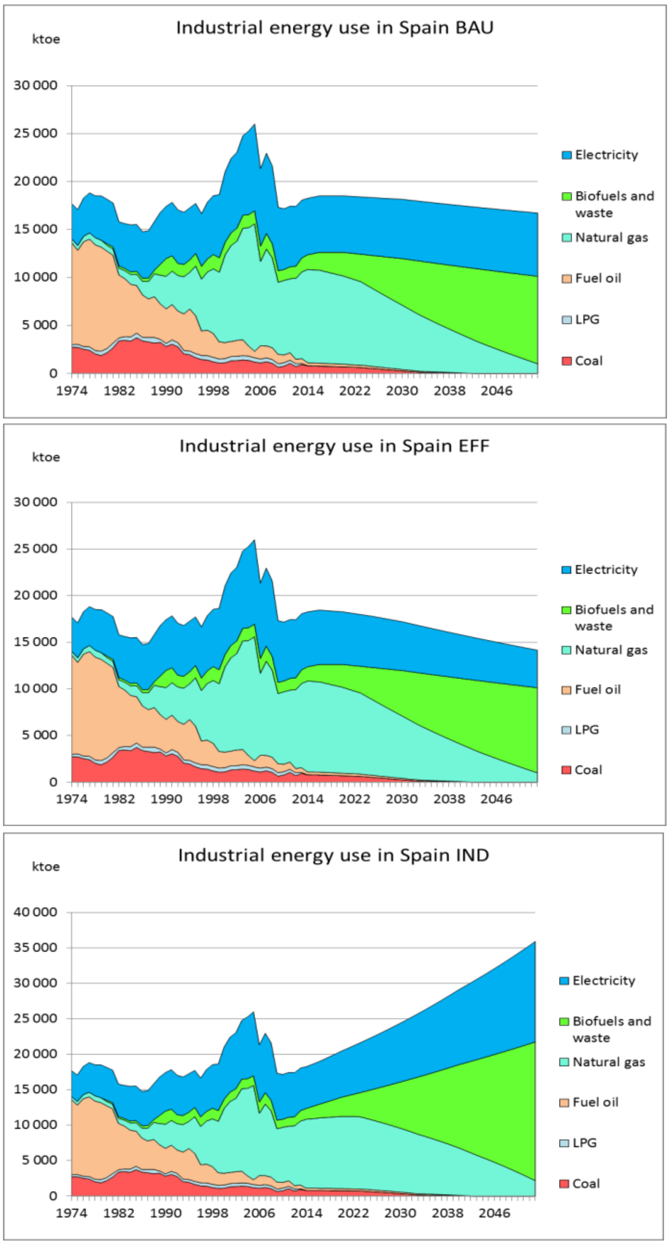

Figure 49. Energy use in the industrial sector in the LINDA Spain BAU, EFF and IND scenarios.

Energy use in the commercial sector in different scenarios is shown in Figure 50. In the IND scenario, energy use in the commercial sector is the smallest, because this sector has a higher growth rate in the other scenarios. In the EFF and IND scenarios, energy use in the commercial sector starts to decline because the efficiency improvements cancel the impacts of economic growth. In the commercial sector, energy consumption is mainly consumption of electricity.

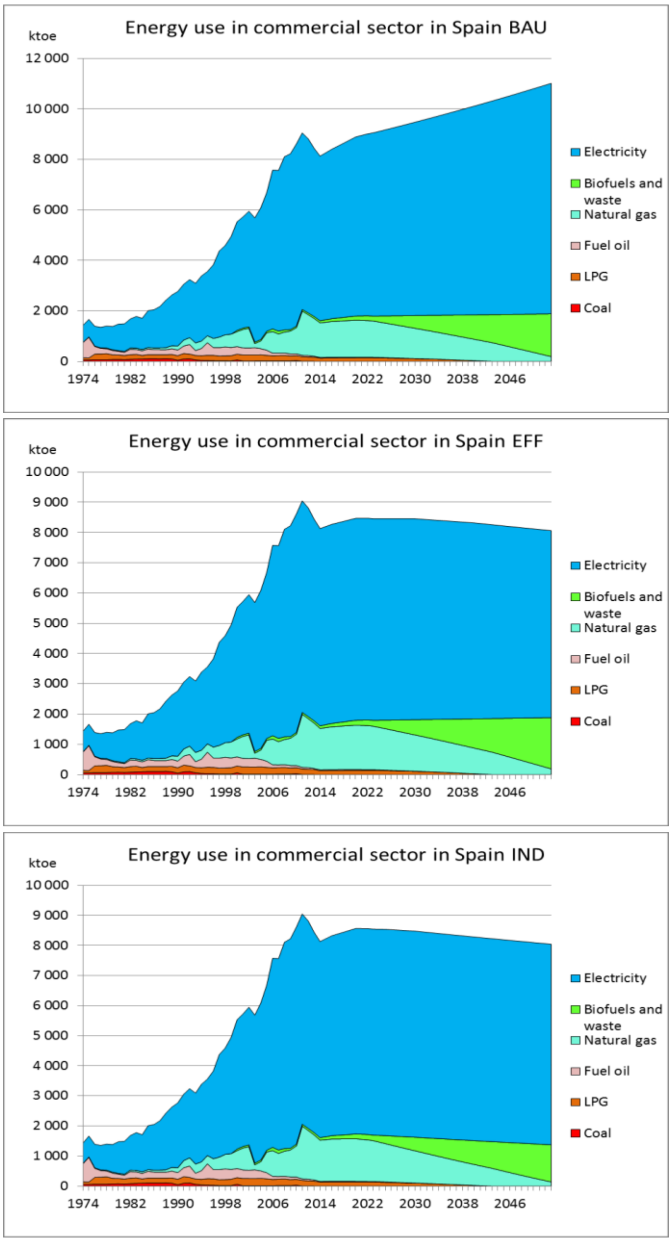

Figure 50. Energy use in the commercial sector in the LINDA Spain BAU, EFF and IND scenarios.

In the LINDA Spain EFF and IND scenarios, the residential electricity use grows more slowly than in the BAU scenario, due to an assumed fast introduction of more efficient electric appliances (Figure 51). There are no other differences between the scenarios. In all scenarios, almost all natural gas will be replaced by biofuels by the end of the scenario period.

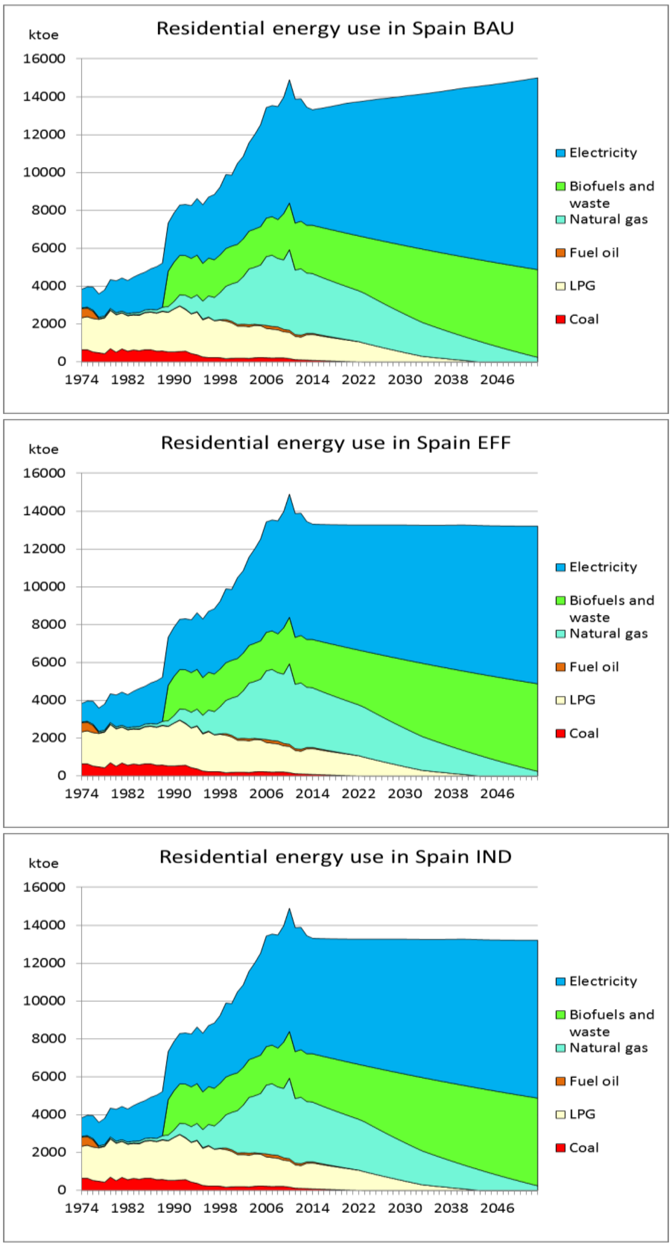

Figure 51. Energy use in the residential sector in the LINDA Spain BAU, EFF and IND scenarios.

The CO_2 emissions in the different scenarios follow the path of the fossil fuel use. The decrease of emissions in the EFF scenario is the largest, and in the IND scenario the smallest (Figure 52).

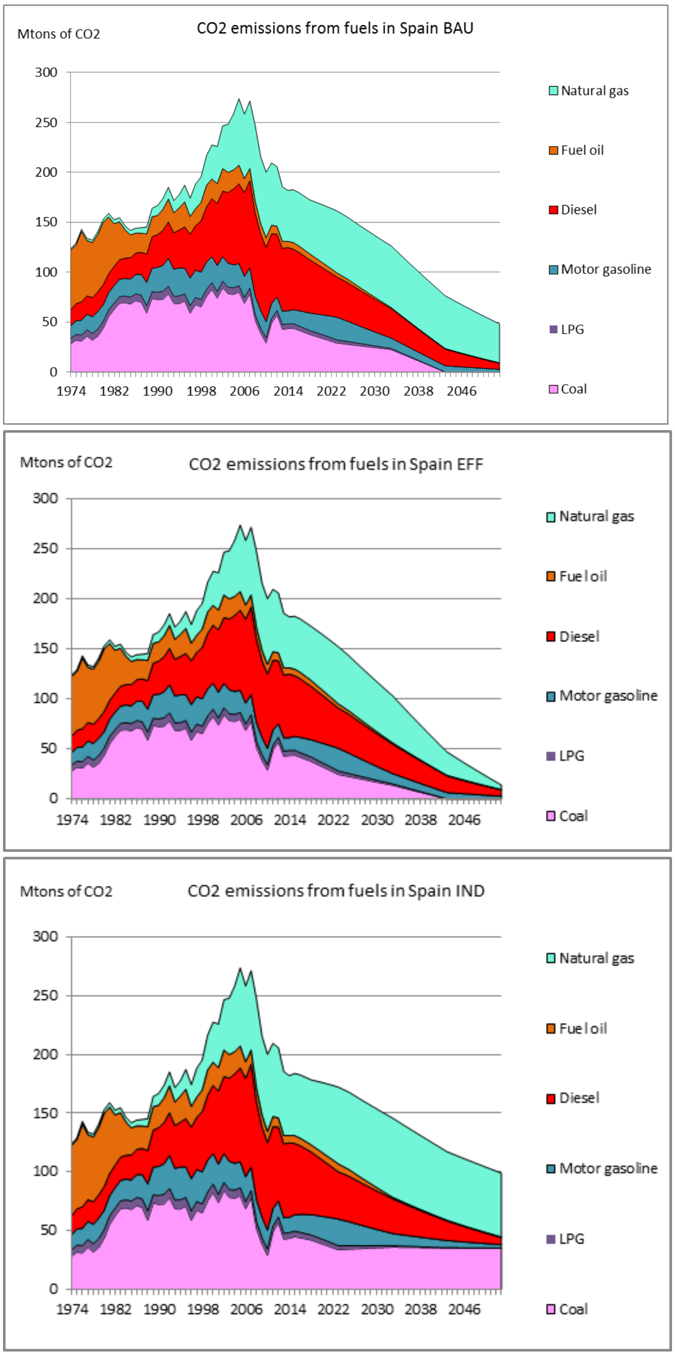

Figure 52. CO_2 emissions from fuel combustion in the LINDA Spain BAU, EFF and IND scenarios.

In the different scenarios the electricity production is planned so that the needed import of electricity (Import = Demand – Production) is similar in order to make the scenarios comparable. This is achieved by changing the capacity factors of the fossil fuel power plants. The actual power plant capacities are assumed to be similar in all the LINDA Spain scenarios. The recent high electricity import in Spain starts to decrease soon all scenarios, and in the early 2030's, import starts to increase again (Figure 53).

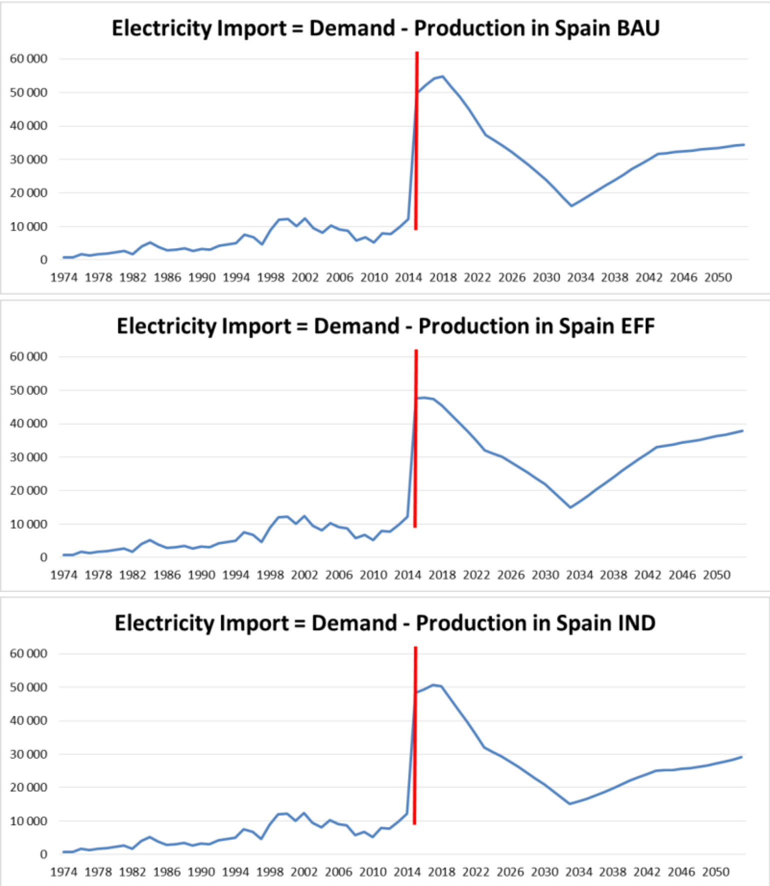

Figure 53. Electricity imports in the LINDA Spain BAU, EFF and IND scenarios.

The installed power plant capacity is shown is Figure 54. The installed capacity in Spain is increasing only for solar and wind power, but the capacity factor of fossil fuel power plants is adjusted to have similar amount of imported electricity in all the LINDA Spain scenarios, BAU, EFF and IND.

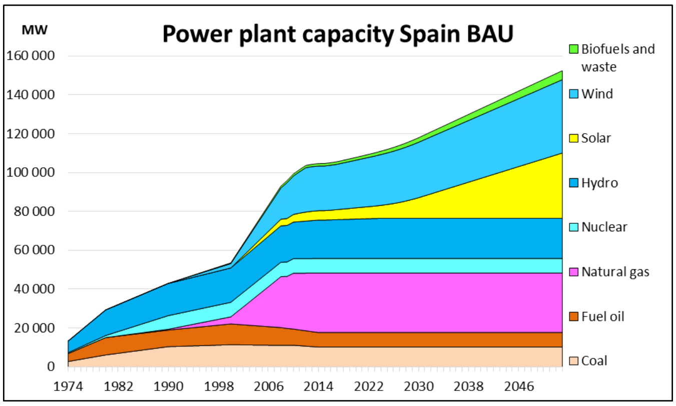

Figure 54. Power plant capacity in the LINDA Spain scenarios.

The development of energy efficiency indicators in different LINDA Spain scenarios is shown in Figure 55. Primary energy intensity (TPES/GDP), final energy intensity (FEC/GDP), and the ratio of TPES/GDP (describing the efficiency of the entire energy transformation system) have all decreasing trends in all scenarios. The lowest values are in the EFF scenario, where energy demand is lower than in the other scenarios.

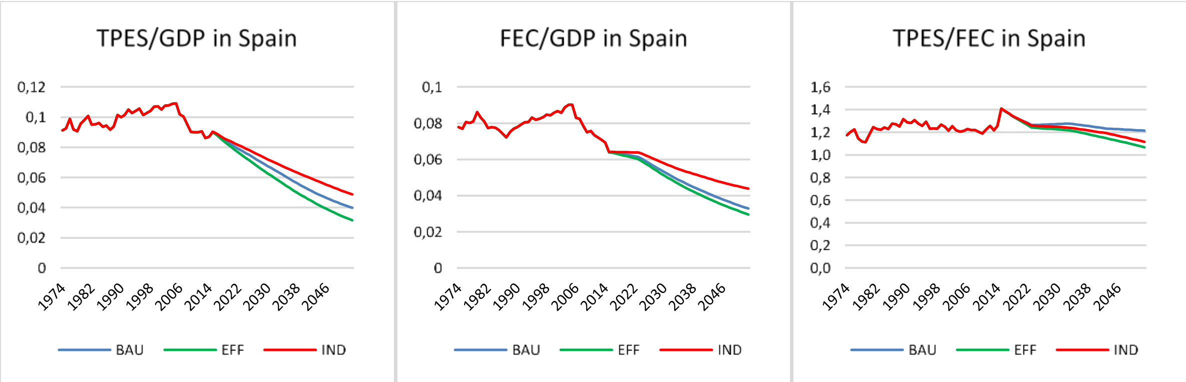

Figure 55. Primary energy intensity (TPES/GDP), final energy intensity (FEC/GDP) and the TPES/FEC ratio in the LINDA Spain BAU, EFF and IND scenarios.

Improvement in energy efficiency in different scenarios, measured as a reduction of energy intensity (TPES/GDP), is shown in Figure 56. The scenario value of energy intensity in the year 2030 is compared to the historical values in the years 1990, 2005 and 2010. Because energy intensity in Spain increased up to the year 2005, the largest improvements can be seen when the 2030 value is compared to the 2005 value. In the BAU scenario, efficiency improvement compared to 2005 is about 38 %, in the EFF scenario about 43 %, and in the IND scenario about 34 %.

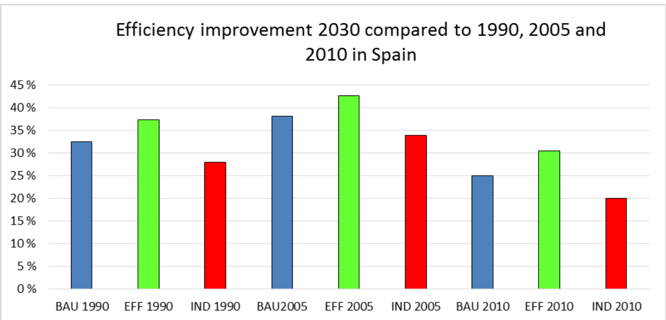

Figure 56. Improvements in energy efficiency in the LINDA Spain BAU, EFF and IND scenarios, primary energy intensity (TPES/GDP) in 2030 in comparison to energy efficiency in 1990, 2005 and 2010.

Conclusions

On the basis of the LINDA modeling work, using economic projections derived from the EU Reference Scenario 2016 and historical trends of sectoral energy intensity improvements, the CO_2 target stipulated in the EU 2030 climate and energy policy framework seems to be very feasible. The target of a 40 % reduction in CO_2 emissions is met even if fast economic growth is assumed in the industrial sector. On the other hand, energy efficiency targets, operationalized as absolute reductions in primary energy and final energy use from the 2005 level, are more challenging.

In the LINDA projections presented in this deliverable, targets for both final energy use (FEC) and primary energy (TPES) are only met if the very favourable trends of changing energy intensity (electricity intensity and fuel intensity) during the period 2009−2014 are assumed to continue up to the year 2030. The final energy use related target of a 17 % cut compared to 2005 is met with different sets of assumptions, while the targeted 23 % cut for primary energy use would require more policy action, and a different profile for power plant investment and different capacity factors than what is presented in the EU Reference Scenario 2016.

Heavy investing in renewable energy capacity and bringing the share of nuclear energy down in the EU energy mix are necessary both for attaining the targeted share of 27 % of renewable energy and reaching the targeted cut in primary energy use. The statistical procedure, where electricity produced by renewables is calculated as primary energy with a coefficient 1, is of key importance here. The energy efficiency targets expressed as absolute reductions in primary energy and final energy consumption can be reached in a number of ways from the modelling perspective.

The sectoral emphasis of economic growth is of central importance in determining how attainable the energy efficiency targets are. If economic growth in the industrial sector during the period 2015-2030 is faster than during the years 2009-2014, it will be significantly more difficult to meet the targets. Also a strong economic growth overall might make the energy efficiency targets unattainable, if unaccompanied by policies significantly boosting the improvement of energy efficiency.

All what is said above is more or less relevant also at the Member State level, but absolute targets for the primary energy and final energy use in the year 2030 are not decided at the Member State level yet.

References

Ang, B.W. (2004). Decomposition analysis for policymaking in energy: which is the preferred method? Energy Policy 32(9), 1131–1139.

European Commission (2012). Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Official Journal of the European Union L 315/1, 14.11.2012.

European Commission (2016a). EU Reference Scenario 2016. DG for Energy, DG for Climate Action and DG for Mobility and Transport.

European Commission (2016b). Proposal for a directive of the European Parliament and of the Council amending Directive 2012/27/EU on energy efficiency. European Commission.

European Commission (2017a). Energy Efficiency Directive. Webpage at https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive. Accessed on 21.8.2017.

European Commission (2017b). 2030 climate & energy framework. Available at: https://ec.europa.eu/ clima/policies/strategies/2030_en. Accessed on 23.8.2017.

E3MLab (2016). PRIMES model: Version 6, 2016-2017, detailed model description.

Future Energy (2017). Your guide to the World beyond fossil fuels. Oslo: Bonnier Publishers International.

IEA (2016). Energy balances of OECD countries and Energy balances of non-OECD countries. International Energy Agency, online data service.

Kaivo-oja, J., Luukkanen, J. & Malaska, P. (2001a). Sustainability Evaluation Frameworks and Alternative Analytical Scenarios of National Economies. Population and Environment. A Journal of Interdisciplinary Studies 23(2), 193–215.

Kaivo-oja, J., Luukkanen J. & Malaska, P. (2001b). Advanced Sustainability Analysis. In M.K. Tolba (Ed.) Our fragile world. Challenges and opportunities for sustainable development. Encyclopedia of Life Support Systems and Sustainable Development. Vol 2. Oxford: EOLSS Publishers Co. Ltd.

Kasanen, P. (1990). Definition of energy saving. Research Institute of the Finnish Economy (ETLA), ETLA Discussion Papers 316. Helsinki (in Finnish).

Kaya, Y. (1990). Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios. Energy and Industry Subgroup, Response Strategies Working Group. Paris: IPCC.

Sun, J.W. (1996). Quantitative analysis of energy consumption, efficiency and savings in the world, 1973–1990. Turku School of Economics Press, series A-4: 1996.

Sun, J.W. (1998). Changes in Energy Consumption and Energy Intensity: A Complete Decomposition Model. Energy Economics, pp. 85-100.

Ulgiati, S., Fiorentino, G., Ripa, M., Viglia, S., Vassillo, C., Rallo, R., Corcelli, F., Leccisi, E., Buonocore, E., Ghisellini, P. (2016). Regional case studies of energy efficiency in Europe – Analysis of the energy efficiency barriers at the regional level. EUFORIE Project. European Union H2020 R&D programme. Deliverable 3.1. University Parthenope of Naples.

Vehmas, Jarmo & Malaska, Pentti & Luukkanen, Jyrki & Kaivo-oja, Jari & Hietanen, Olli & Vinnari, Markus & Ilvonen, Jenni (2003). Europe in the Global Battle of Sustainability: Rebound Strikes Back? Advanced Sustainability Analysis. Publications of the Turku School of Economics and Business Administration, Series Discussion and Working Papers 7:2003.

Vehmas, Jarmo, Luukkanen, Jyrki, Kaivo-oja, Jari & Heino, Hanna (2016). Energy efficiency trends and their drivers in the EU-28 Member States. Horizon2020 project 649342 EUFORIE, Deliverable D2.1. Available at http://www.euforie-h2020.eu.

Jarmo Vehmas, Sergio Ulgiati, Mario Giampietro, Sylvia Lorek, Maria Ameziane, Chiara Vassillo, Raúl Velasco-Fernández, Maddalena Ripa, Sandra Bukkens & Joachim Spangenberg (2017). Summary report of the national participatory EUFORIE workshops. European Futures for Energy Efficiency (649342 EUFORIE), Deliverable 7.1.

Waggoner, P. E. & Ausubel, J. H. (2002). A framework for sustainability science: A renovated IPAT Identity, Proceedings of the National Academy of Sciences, 99(12), 7860–7865.

York, R., Rosa, E.A. & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecological Economics 46(3), 351–365.