QUANTIFICATION OF SYNERGIES BETWEEN ENERGY EFFICIENCY FIRST PRINCIPLE AND RENEWABLE ENERGY SYSTEMS

D3.2

Beta version of the model IndustryPLAN

Project

Acronym	**sEEnergies**
Title	Quantification of Synergies between Energy Efficiency First Principle and Renewable Energy Systems
Coordinator	Brian Vad Mathiesen, Aalborg University
Reference	846463
Type	Research and Innovation Action (RIA)
Programme	HORIZON 2020
Topic	LC-SC3-EE-14-2018-2019-2020 - Socio-economic research conceptualising and modelling energy efficiency and energy demand
Start	01 September 2019
Duration	30 months
Website	https://seenergies.eu/
Consortium	**Aalborg Universitet (AAU),** Denmark **Hogskolan i Halmstad (HU),** Sweden **TEP Energy GmbH (TEP),** Switzerland **Universiteit Utrecht (UU),** Netherlands **Europa-Universität Flensburg (EUF),** Germany **Katholieke Universiteit Leuven (KULeuven),** Belgium **Norges Miljø- og Biovitenskapelige Universitet (NMBU),** Norway **SYNYO GmbH (SYNYO),** Austria **Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. (Fraunhofer),** Germany

Deliverable

Number	**3.2**
Title	**Beta version of the model IndustryPLAN + report**
Lead beneficiary	Aalborg University
Work package	WP3
Dissemination level	Public
Nature	Other
Due date	31.03.2020
Submission date	31.03.2020
Authors	**Rasmus Magni Johannsen (AAU)** **Iva Ridjan Skov (AAU)** **Brian Vad Mathiesen (AAU)**
Contributors	
Reviewers	**Urban Persson (HU)** **Tobias Fleiter (Fraunhofer ISI)**

Document history

Version	**Date**	**Comments**
1	20-03-2020	Internal draft to reviewers

Acknowledgement: This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 846463.

Contents

Figures

Tables

Acronyms & Abbreviations

Term	Description
DH	District heating
EE	Energy efficiency
PBT	Payback time
HP	Heat pump
COP	Coefficient of performance
$T_{HighMean}$	Average DH forward temperature
$T_{LowMean}$	Average temperature of heat source
$T_{HighOutlet}$	Forward temperature from HP
$T_{HighInlet}$	Return temperature into HP
$T_{LowOutlet}$	Temperature heat source being cooled from
$T_{LowInlet}$	Temperature heat source being cooled to

1 Introduction

Industries globally account for upwards of one-third of the global energy demand, making the industrial energy demand a critical part of the energy system. Despite this, energy system models have so far largely de-emphasised the importance of the industrial sector, leaving the industrial energy sector as an unknown black box. This may be for several reasons including the lack of access to high-quality disaggregated industrial energy demand data, or due to the inherent difficulties of analysing the industrial sector as it is comprised of a multitude of technologies and processes. Future energy system models will, however, need to encompass all energy sectors, not only the electricity and heat sectors, to enable holistic and integrated energy planning for future renewable energy systems.

The IndustryPLAN tool targets the lacking middle ground between highly site-specific analyses of individual production facilities and generalized nationally aggregated analyses. The purpose of the IndustryPLAN tool is to expand on the black box of industry and provide a framework for developing sub-sector specific analyses on both a country-specific and European level.

Applying the energy efficiency first principle, the IndustryPLAN tool provides a framework for investigating the industrial energy sector in the context of the renewable energy transition. The user is provided with a flexible platform for developing future industry energy scenarios based on a range of potential energy efficiency measures.

This report introduces the purpose, functioning, and output of the IndustryPLAN tool. The tool is accompanied by a beta version of the IndustryPLAN tool. Due to the nature of being a beta-version, certain functionalities are not incorporated into the tool at this stage, and continued development will take place as the tool is being finalized. The tool is available upon request to the project coordinator of sEEnergies.

2 Tool overview

IndustryPLAN is a tool for analysing industrial energy demands of European countries. The tool is developed as a Microsoft Excel spreadsheet using a combination of Excel functions and VBA coding, making the tool accessible for a wide audience.

Some of the main qualities of IndustryPLAN are:

- Provides easy access to sub-sector specific energy demand data for all countries of the European Union.
- Enables analysis of energy demands at a country level and European level.
- Allows for analysis of heat flows and excess heat potentials at different temperature levels.
- Provides a platform for the development of energy efficiency scenarios based on a range of energy efficiency measures.
- Provides data inputs for further integrated energy modelling in EnergyPLAN.

Figure 1 provides an overview of the main data inputs to IndustryPLAN and the main outputs.

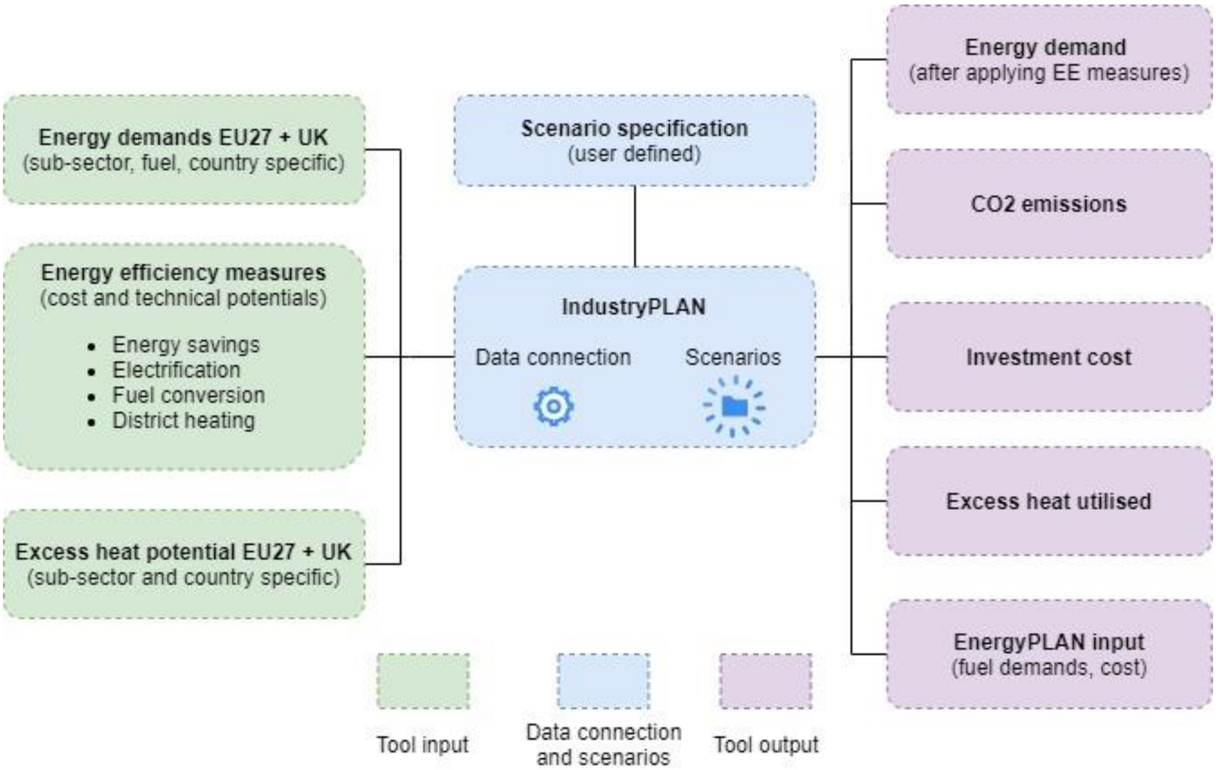

Figure 1: Overview of IndustryPLAN model.

As can be seen in Figure 1, IndustryPLAN provides many different results aimed at evaluating and quantifying future industrial energy demands. Combined with the included scenario design functionality, these outputs can aid in the investigation of a wide array of research questions. This may, for example, include analyses on the importance of energy savings, the impact of extensive electrification or conversion of fossil fuel-based processes to biomass and hydrogen-based processes. While such analyses and results specifically for the industry sector are interesting on their own, an important output of IndustryPLAN is an input provided for EnergyPLAN; a tool capable of encompassing complete national energy systems, including the heat, electricity, industry, and transport sectors. Thus, the disaggregated and detailed industry assessment from IndustryPLAN can provide a more thorough representation of the industry sector when investigating integrated energy systems in EnergyPLAN.

2.1 Energy efficiency measures

IndustryPLAN includes four main energy efficiency measures:

- Energy savings
- Electrification
- Fuel conversion (biomass, hydrogen)
- Excess heat extraction for district heating

The user can decide the extent to which these energy efficiency measures are to be implemented, however subject to some technical boundaries such as what is technically feasible. The user may for example design one scenario where the complete technical potential for energy savings is implemented, to see how the energy demand compares to a scenario where no energy savings are implemented.

2.2 Data inputs and calculations

IndustryPLAN relies on a range of data inputs, most of which are included with the tool. By default, the tool includes energy demands on sub-sector level for European countries and estimates of excess heat potential. The user will need to provide some inputs such as assumed fuel prices and general district heating forward and return temperatures for the country and scenario being investigated. Other assumptions, such as investment costs for heat pumps and heat exchangers, energy savings potential, fuel emission factors etc. are included in the tool but can be altered by the user as needed.

IndustryPLAN applies a hierarchical prioritization of energy savings measures, with measures prioritized as follows:

1. Energy savings
2. Electrification
3. Fuel conversion (biomass, hydrogen)
4. Excess heat extraction for district heating

Energy savings will thus be prioritized the highest, followed by electrification, etc. Calculations are performed based on this prioritization principle as well, with energy savings being implemented before any potential electrification occurs. In addition to these energy efficiency measures, IndustryPLAN includes an option of projecting the baseline energy demand. This can be included if the user wants to align the baseline demand data to a specific future projection, for example, the PRIMES 2050 projections. If the user includes such a projection, this projection is calculated before any of the energy efficiency measures are applied. Thus, in reality, the very first step of the model is the projection of the baseline energy demand, followed by the four prioritized energy efficiency measures.

3 Input data description

The following describes the main input data and assumptions needed to use the IndustryPLAN tool, and documents how these are incorporated into the tool.

3.1 Energy demand

The main tool input is the energy demand per industry sub-sector distributed by fuel type. This data is included with the tool for all EU27 countries and the United Kingdom, thus the user will simply need to select which country should be analysed. If relevant, the user can then make adjustments to the demand data, e.g. if more recent numbers have been identified. The industrial energy demand is disaggregated into the following sub-sectors:

- Chemicals
- Iron and steel
- Non-ferrous metals
- Non-metallic minerals
- Paper and pulp
- Others

The energy demand included is calculated as final energy demand based on PRIMES 2016 data, using 2015 as a base year. The fuel-specific breakdown per sub-sector is based on IEA Energy Balances. Energy demand is included in 5-year intervals up to 2050.

Energy demands are included as final energy demands and are further disaggregated by the type of energy used according to the following energy types:

- Coal and coal products
- Oil products
- Natural gas
- Biofuels and waste
- Peat and peat products
- Heat
- Geothermal
- Solar/wind/other
- Electricity

Further details on the methodology behind the industrial energy demand assessment can be found in the report sEEnergies D3.1 *"Analysis and results of the reference scenarios assessment"* [1].

3.2 Energy demand projection

IndustryPLAN includes the option of projecting energy demands based on a frozen efficiency assumption, taking a starting point in a base year and applying an annual growth rate, positive or negative, depending on future expectations. These demand projections are sub-sector specific, as future developments may be very sub-sector specific. The development is assumed to be exponential, e.g. a 1% annual increase is based on the year prior and not the original baseline year. This can then be aligned to the PRIMES demand projections for up to 2050, or any other projections if the user wants to compare different demand projections.

3.3 Energy savings potential

In IndustryPLAN Energy savings are defined solely as internal (on-site) energy efficiency improvements, such as replacing older installations with state-of-the-art technologies, implementing integrated control systems, flue gas monitoring, or sub-metering. This does not include conversion of fuels from fossil fuels to electricity, as this will be included as electrification and fuel conversion measures specifically. Assumptions on energy savings potential are based on the report *"Study on energy efficiency and energy saving potential in industry and on possible policy mechanisms"* by the European Commission Directorate-General Energy [2]. Table 1 includes an overview of the technical potential assumed per sub-sector categorized according to payback time (PBT).

Table 1: Energy savings potential included [2].

Energy savings potential	2 yr PBT	5 yr PBT	Technical potential
Sub-sectors	**[%]**	**[%]**	**[%]**
Chemicals	7.9%	9.3%	22.0%
Iron and steel	8.6%	9.4%	26.0%
Non-ferrous metals	12.0%	12.7%	21.0%
Non-metallic minerals	6.6%	7.2%	18.0%
Others	10.3%	13.4%	24.5%
Paper and pulp	5.8%	7.1%	17.0%

In IndustryPLAN the user specifies a desired level of energy savings to be implemented. This may, for example, be the potential with a 2-year payback time, the entire technical potential, or any number in between. Based on the fuel prices defined in the tool and the payback time of the energy savings, an estimated investment cost is calculated. It is assumed that the technical potential can be realised with a 10-year payback time, as a specific payback time is not specified in the report.

The energy savings are assumed to be implemented linearly towards 2050.

3.4 Electrification

This functionality has not been implemented for the beta version of the tool.

3.5 Fuel conversion

This functionality has not been implemented for the beta version of the tool.

3.6 Excess heat

IndustryPLAN includes a data set on excess heat potential for the industrial sub-sectors, enabling the user to define scenarios with varying excess heat utilisation in district heating. While this does not as such increase the energy efficiency of the industrial energy sector on its own, the increased use of excess heat improves energy efficiency in the scope of the entire energy system. As such, the utilisation of excess is defined as an external (off-site) energy efficiency improvement. The potential for excess heat in district heating estimated in IndustryPLAN can furthermore be translated to function as an EnergyPLAN input, and thus assist in quantifying the benefits of excess heat utilisation in a broader energy system perspective.

Estimations on the excess heat potential per sub-sector are included in the tool for three temperature levels; 25°C, 55°C, and 95°C. Further details on this data set can be found in the sEEnergies D5.1 report

"Documentation on excess heat potentials of industrial sites including open data file with selected potentials" [3].

IndustryPLAN includes both economic and technical assumptions used to estimate the required heat pump capacity as a function of the chosen level of excess heat extraction. The user decides whether to implement heat pumps along with the excess heat extraction. If heat pumps are not implemented, it is assumed that the excess heat is used directly in district heating. In that case, the user needs to consider whether it is feasible to utilise the excess heat in practice. It may for example be impractical to use excess heat at 25°C and 55°C in district heating systems with significant higher forward temperatures, without also including heat pumps to increase the temperature of the supplied excess heat.

If heat pumps are included, it is assumed that the excess heat will function as a heat source for the heat pump supplying heat at the designated district heating forward temperature. Heat pumps are assumed to be electric, which in turn increases the electricity demand. Based on the theoretical Lorentz efficiency and heat pump efficiency a COP value is calculated for the heat pumps. This is based on a range of technical assumptions. Based on assumed investment costs for heat pumps and heat exchangers and total thermal capacity an investment cost is calculated.

Technical and economic assumptions for the heat pump modelling in IndustryPLAN are based on three Danish examples where heat pumps for district heating were implemented together with excess heat recovery from industries. The examples cover excess heat temperatures ranging from 20°C-55°C, and three different industries; a paper factory [4], a biopharmaceutical factory [5], and a glass production factory [6]. Table 2 shows the primary economic assumptions included. These values can be changed as needed.

Table 2: Key economic assumptions for heat pumps in IndustryPLAN.

Technologies	[M€/MW]
Heat pump	0.66
Heat exchanger	0.10

The primary technical inputs needed for the Lorentz calculations can be seen in Table 3. These include district heating forward and return temperatures, with typical temperatures for Denmark show in Table 3. Based on the Danish district heating examples typical values for cooling of the excess heat source (delta t) and heat pump efficiency is included; these can, however, be adjusted as needed.

Table 3: Key technical assumptions for heat pumps in IndustryPLAN.

Technical assumptions	Forward temperature [°C]	Return temperature [°C]	Operational hours [h/yr]
District heating	75	35	6,500

Heat pumps	25°C	55°C	95°C
Delta t [°C]	10	30	60
Heat pump efficiency	45%	40%	30

Figure 2 shows the functioning principle of the electric heat pumps as designed in IndustryPLAN.

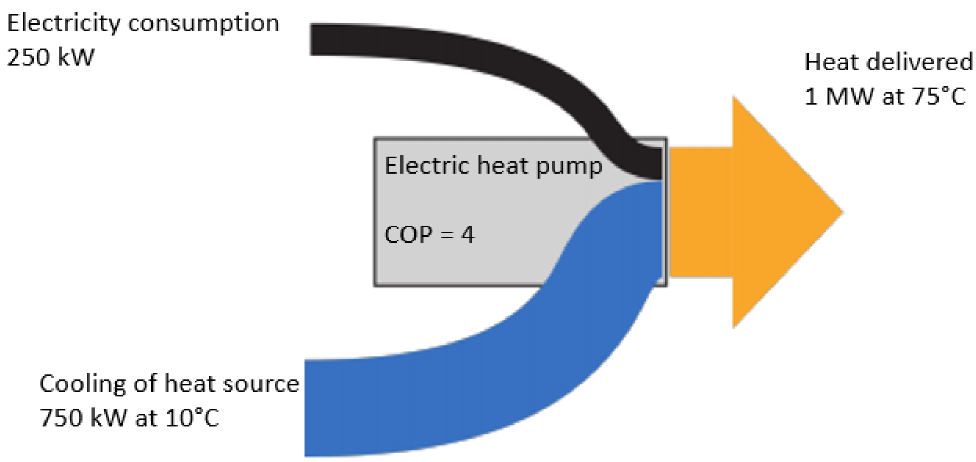

Figure 2: Principle of heat pump modelling [7].

A heat pump COP value is calculated for each of the three temperature levels (25°C, 55°C, and 95°C) based on a theoretical maximum Lorentz efficiency. Main inputs for this is the district heating forward and return temperatures along with the temperature of the excess heat source and the cooling of this. The Lorentz efficiency is calculated as seen in Eq. 1.

$$\boldsymbol{COP\ (Lorentz) = \frac{T_{HighMean}}{T_{HighMean} - T_{LowMean}}}$$

Eq. 1

Where $T_{HighMean}$ is the average forward temperature and $T_{LowMean}$ is the average temperature of the heat source.

$T_{HighMean}$ and $T_{LowMean}$ can be calculated as seen in Eq. 2.

$$\boldsymbol{T_{HighMean} = \frac{T_{HighOutlet} - T_{HighInlet}}{ln(\frac{T_{HighOutlet}+273{,}15}{T_{HighInlet}+273{,}15})}}$$ **Eq. 2**

Where $T_{HighOutlet}$ is the forward temperature from the heat pump and $T_{HighInlet}$ is the return temperature into the heat pump. In the same way, $T_{LowMean}$ can be calculated as seen in Eq. 3.

$$\boldsymbol{T_{LowMean} = \frac{T_{LowOutlet} - T_{LowInlet}}{ln(\frac{T_{LowOutlet}+273{,}15}{T_{LowInlet}+273{,}15})}}$$ **Eq. 3**

Where $T_{LowOutlet}$ is the temperature the heat source is being cooled from, and $T_{LowInlet}$ is the temperature the heat source is being cooled to.

The output of the heat pump modelling is an estimation of the required heat pump capacity, annual heat production per temperature level a resulting increase in electricity demand, and an estimated investment cost. These can then function as inputs for EnergyPLAN and further analysis.

4 Tool output

The following describes the main outputs and results provided by the IndustryPLAN tool.

4.1 Energy demand

Final energy demand will be available for each sub-sector in 5-year intervals, below an example of the expected output can be seen.

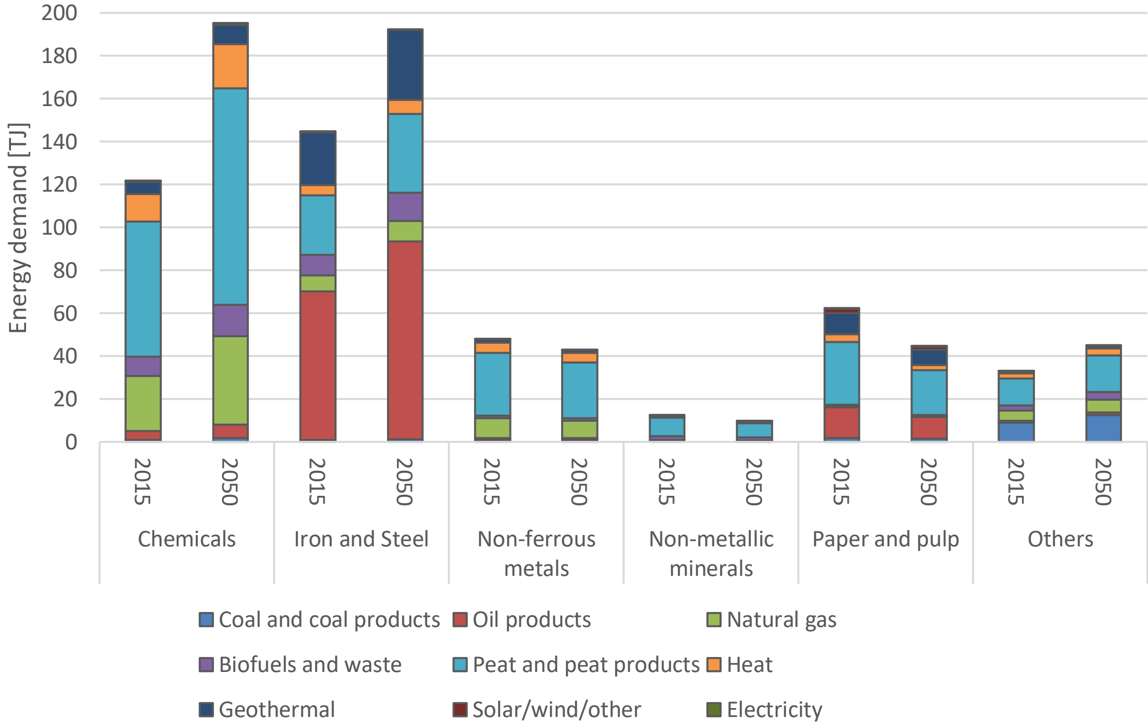

Figure 3: Expected final energy demand output (numbers for illustrative purposes).

Results for the CO_2 emission per sub-sector and energy type will for the final version also be available in 5-year intervals.

4.2 EnergyPLAN input

One of the outputs of IndustryPLAN is an input for EnergyPLAN where further integrated energy system modelling can be conducted. This allows for analyses of how the industrial energy sector interacts with the surrounding energy system. For the beta version, this functionality is not finalized. Table 3 outline the expected technical inputs EnergyPLAN. Inputs mainly relate to the energy demands of the industry sector, but also possible excess heat recovered for district heating is an important input. This format allows for seamless interaction with the EnergyPLAN tool.

Table 4: Expected inputs on energy demands for EnergyPLAN (numbers for illustrative purposes).

Fuel demands (TWh) - for EnergyPLAN				
	Scenario #1	Scenario #2	Scenario #3	Scenario #4
Coal		1.50	12.80	0.00
Oil		11.19	2.00	4.50
Natural gas		10.81	7.10	11.80
Biomass		3.31	0.00	4.40
Hydrogen		0.00	0.00	0.00
Total fuel	18.89	26.81	21.90	20.70
Converted fuels in industry				
District Heat production		0.00	0.00	0.00
Electricity	18.78	20.26	20.38	20.38
Electricity production		1.20	2.30	2.40
District Heat production		1.30	1.50	2.01

Table 4 outlines the economic inputs needed in EnergyPLAN, these economic inputs will be included in the final version of IndustryPLAN.

Table 5: Expected inputs on investment costs for EnergyPLAN (numbers for illustrative purposes).

		Investments M€	Lifetime Years	Annual O&M % of inv.	Annual inv. M€/year	Annual O&M M€/year
				Scenario #1		
1	Electricity savings in industry	1362	45	1%	56	14
2	Fuel savings in industry	16703	40	1%	723	209
3	Conversion to DH	743	45	1%	30	7
4						
5						
6						

4.3 Key-indicators

An interface has been prepared which provides easy access to some key-indicators on the industry energy consumption and enables comparison of analysed scenarios. The purpose of this is to provide an initial overview of the scenarios in a format that is easy to read and understand. It is not a replacement for some of the more detailed results, but for a first understanding or possibly communication purposes these key-indicators may be used.

The key-indicators primarily emphasise results related to CO_2 emissions and renewable energy shares, as these are typically the most effective metrics for communication purposes.

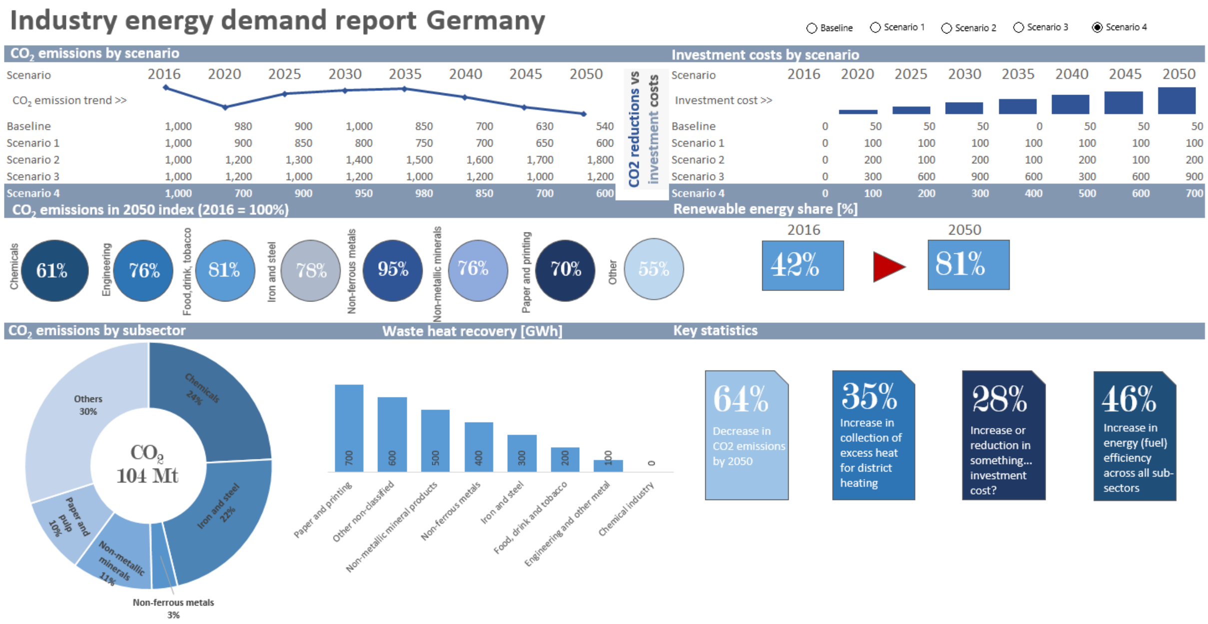

Figure 4: Dashboard with key indicators from IndustryPLAN.

5 Conclusions

An Excel-based IndustryPLAN tool has been prepared, functioning as a proof of concept for the underlying methodology, functionality, and calculations, while illustrating the potential results of the final IndustryPLAN tool. The tool provides access to energy demands for the EU27 countries and the United Kingdom for six industrial sub-sectors further disaggregated by fuel type, demand-type, and temperature level. This demand data functions as the foundation of the tool and baseline scenarios. The tool furthermore includes data on the potential for extraction of excess heat at temperatures of 25°C, 55°C, and 95°C, also disaggregated on a sub-sector level.

The tool enables the user to conduct country-specific as well as aggregated European analyses of energy efficiency measures such as energy savings, excess heat utilisation, and fuel conversion. Tool outputs are primarily: final energy demands after implementation of the specified energy efficiency measures, related investment costs, an input for EnergyPLAN where further integrated energy system analyses can be done, and a graphic overview of industrial key-indicators.

The tool is not yet fully functional in practice, as some of the data inputs and assumptions need further development. This is mainly the case for fuel converting initiatives such as conversion to electricity, biomass, hydrogen, or other alternative fuel types. Furthermore, the calculation module is not yet fully dynamic and interactive. As IndustryPLAN progresses from beta-version to the final version, final data sets, assumptions, and calculation modules will be completed. The present version of the tool is available upon request to the project coordinator.

6 References

[1] Kermeli K, Crijns-Graus W. sEEnergies D3.1 Assessment of reference scenarios for industry. 2020.

[2] European Commission Directorate-General Energy. Study on energy efficiency and energy saving potential in industry and on possible policy mechanisms. 2015.

[3] Fleiter T, Neuwirth M, Mildner F, Manz P, Persson U, Kermeli K, et al. sEEnergies D5.1 Documentation on excess heat potentials of industrial sites including open data file with selected potentials. 2020.

[4] Danish Energy Agency, Grøn Energi. Inspirationskatalog for store varmepumpeprojekter i fjernvarmesystemet. 2017.

[5] HOFOR. Establishing an electric industrial excess heat pump at Novozymes. 2019.

[6] PlanEnergi. Case description excess heat in Fensmark. 2018.

[7] Grøn Energi. Drejebog om store varmepumpeprojekter i fjernvarmesystemet. 2017.