DEEDS Knowledge base

D1.4 DEEDS Knowledge base

DEEDS

Dialogue on European Decarbonisation Pathways

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Contents

Introduction

The aim of the DEEDS project is to provide the DG R&I and the High-Level Panel with state-of-the art knowledge about decarbonisation pathways.

The knowledge base developed in Task 1.3 constitutes the quantitative backbone on which the different activities of this project (WP1-4) can rely. Beyond the direct relevance for the projects' activities, the HLP and the DG R&I, the knowledge base intends to reach out to the academia and the broader audience interested in European decarbonisation pathways and key technologies that could deliver deep and rapid reductions in emissions.

The knowledge base may help stakeholders from industry, policy making and society to access detailed information about expected European emission limits, technology markets and energy prices, to develop long-term strategies based on this information, and understand the market potential for technologies consistent with decarbonization pathways

The knowledge base consists of two components: the scenario explorer and the technology database. This document presents both databases, shows the various applications of the tools and how to withdraw useful information from them.

1 The DEEDS Scenario Explorer

The DEEDS Scenario Explorer (https://data.ene.iiasa.ac.at/deeds-explorer/), hosted by IIASA, and published on the DEEDS website (https://deeds.eu/results/workshop-report-decarbonising-the-energy-sector-through-research-innovation-17-june-2019-brussels-2-2-2/) comprises interactive, accessible and powerful visualization tools for the dissemination of scenario results displaying European decarbonization pathways. Additionally, it includes a video tutorial and this report documentation.

The DEEDS database collects 184 scenarios and 90 variables. Most scenarios available in the DEEDS scenario explorer were first available on the IAMC 1.5°C Scenario Explorer and Data hosted by IIASA or on the CDLINKS Stock Taking Database. We however made sure that the European region is represented explicitly in the DEEDS database, which was not necessarily the case in the original databases. Most of these scenarios have benefited from a European funding (*e.g.* ADVANCE or CD-LINKS scenarios). We are very much indebted to the modelling teams which kindly agreed with the transfer of their scenarios.

In the table below, we provide some information on the scenarios available in the explorer and on the projects they originated from. More information is available on the original databases: IAMC 1.5°C Scenario Explorer and the CDLINKS Stock Taking Database.

Study/model name	Key focus	Scientific references
SSPx-1.9	Development of new community scenarios based on the full SSP framework limiting end-of-century radiative forcing to 1.9 W m^{-2}.	Riahi et al., 2017 Rogelj et al., 2018
ADVANCE	Aggregate effect of the INDCs, comparison to optimal 2°C/1.5°C scenarios ratcheting up after 2020. Decarbonisation bottlenecks and the effects of following the INDCs until 2030 as opposed to ratcheting up to optimal ambition levels after 2020 in terms of additional emissions locked in. Constraint of 400 $GtCO_2$ emissions from energy and industry over 2011-2100.	Vrontisi et al., 2018 Luderer et al., 2018
CD-LINKS	Exploring interactions between climate and sustainable development policies with the aim to identify robust integral policy packages to achieve all objectives. Evaluating implications of short-term policies on the mid-century transition in 1.5°C pathways linking the national to the global scale. Constraint of 400 $GtCO_2$ emissions over 2011-2100.	McCollum et al., 2018
EMF-33	Study of the bioenergy contribution in deep mitigation scenarios. Constraint of 400 $GtCO_2$ emissions from energy and industry over 2011-2100.	Bauer et al., 2018

Study/model name	Key focus	Scientific references
Single-model studies		
IMAGE 1.5	Understanding the dependency of 1.5°C pathways on negative emissions.	Van Vuuren et al., 2018
PIK CEMICS (REMIND)	Study of CDR requirements and portfolios in 1.5°C pathways.	Strefler et al., 2018
PIK PEP (REMIND-MAgPIE)	Exploring short-term policies as entry points to global 1.5°C pathways.	Kriegler et al., 2018

The DEEDS Scenario Explorer proposes a user-friendly interface. In the following, we introduce some of the features of the Scenario Explorer.

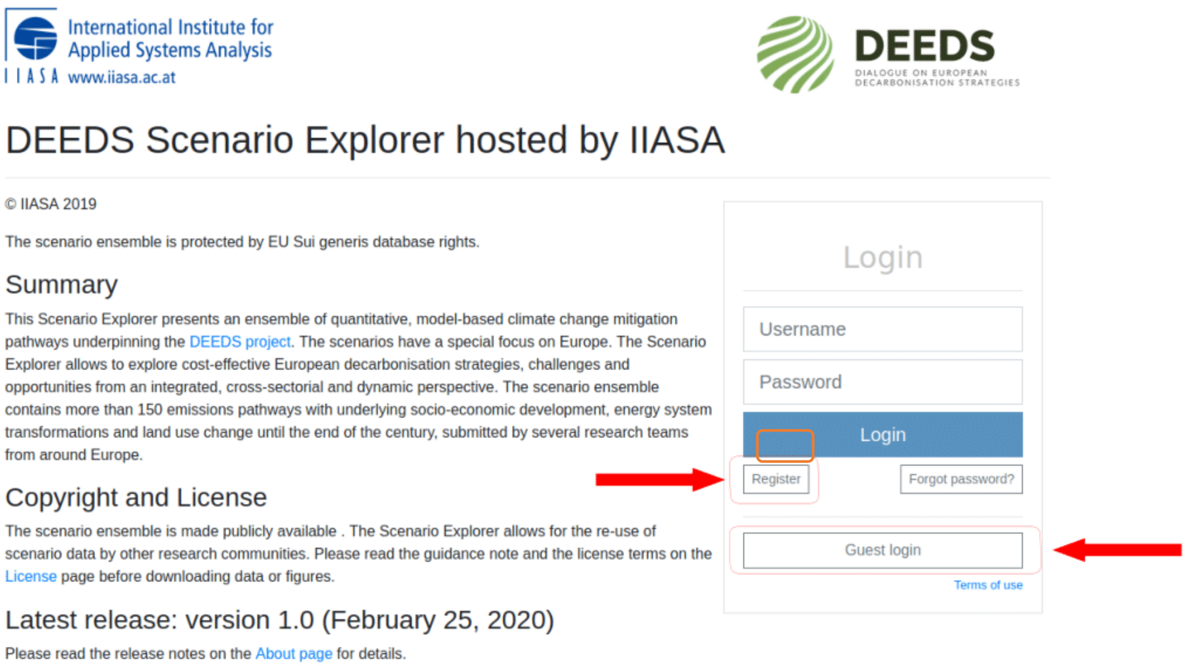


Figure 1 Login interface

After logging in (by registering or entering as "guest user" as highlighted in the figure), the user can create a new workspace. A workspace is a collection of panels. Each panel can display a bar plot, a line plot, a table or some text. A workspace is a useful tool to investigate the different facets of a topic. Each workspace can be saved so that the user can continue the analysis in a subsequent session.

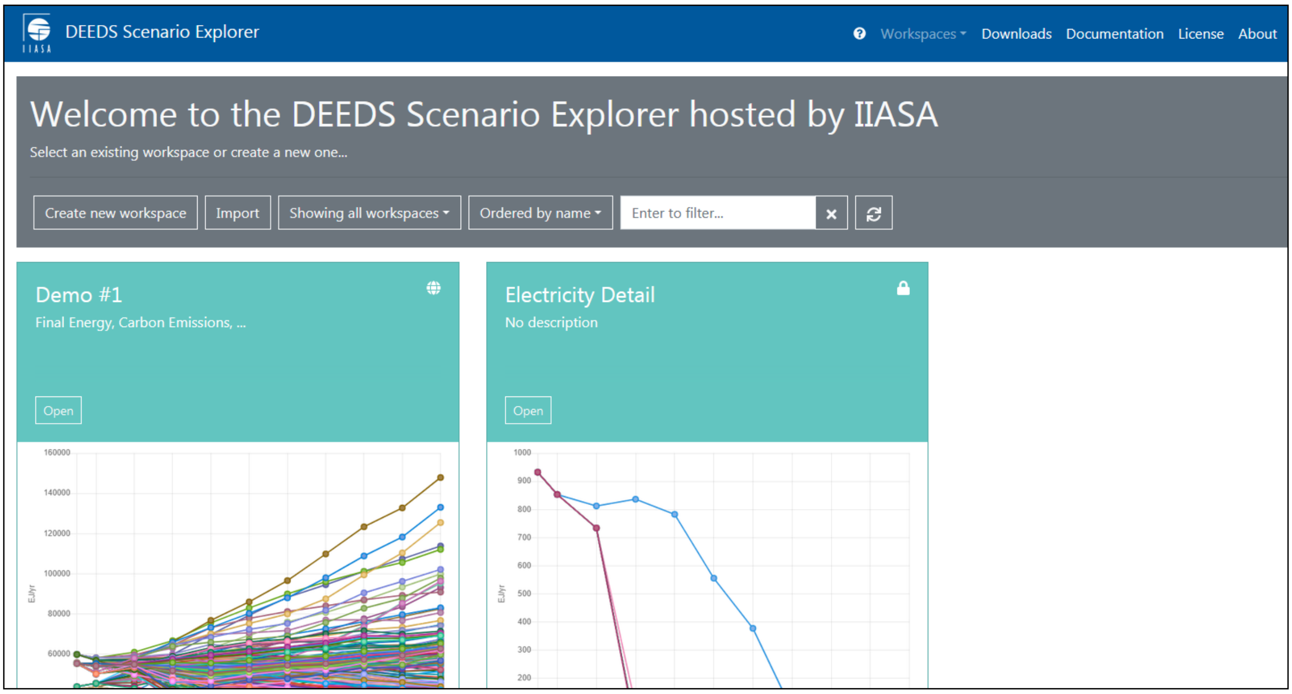


Figure 2 Overview of workspaces accessible to the user

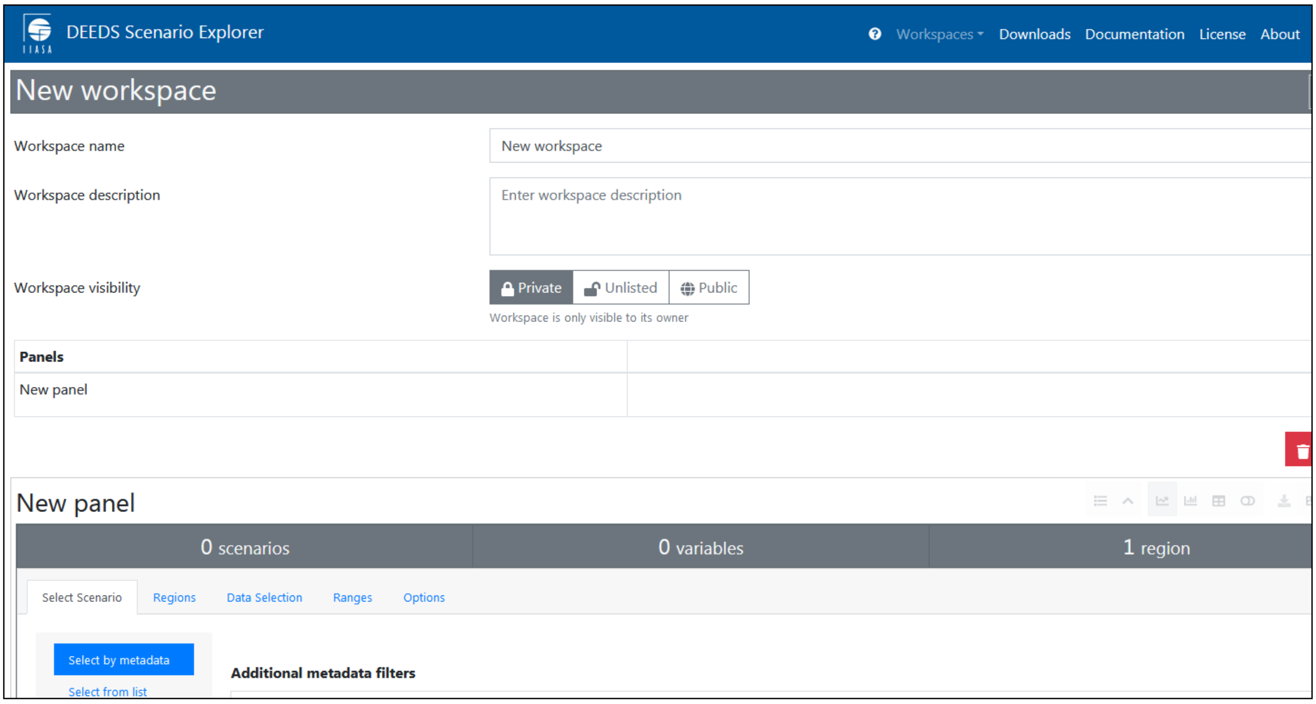


Figure 3 Creation of a new workspace

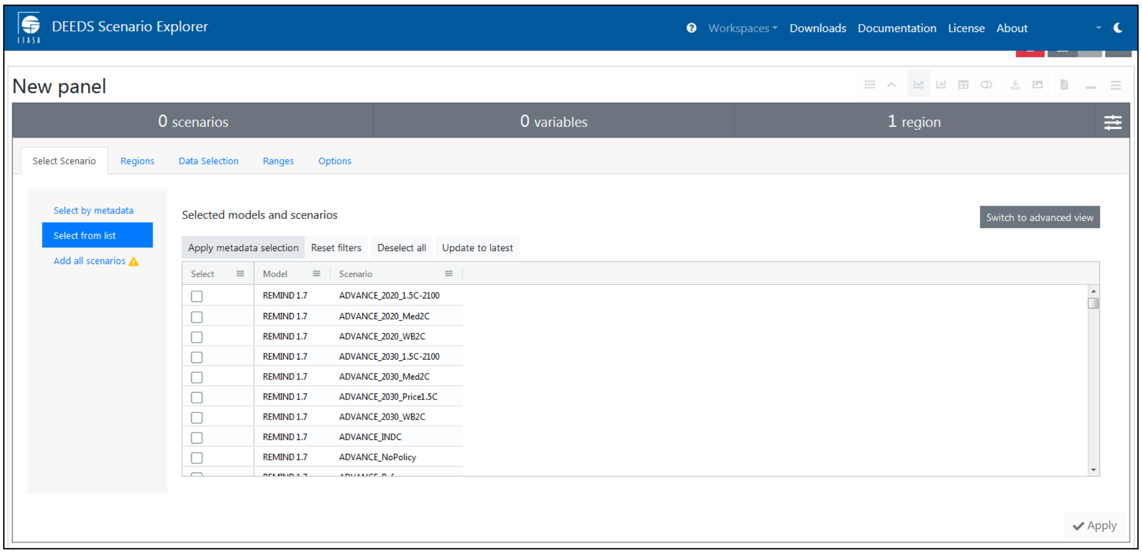


Figure 4 Creation of a new panel. The user may select the scenarios of interest

When creating a new panel within a workspace, the user may choose among the list of scenarios, variables and regions available in the database.

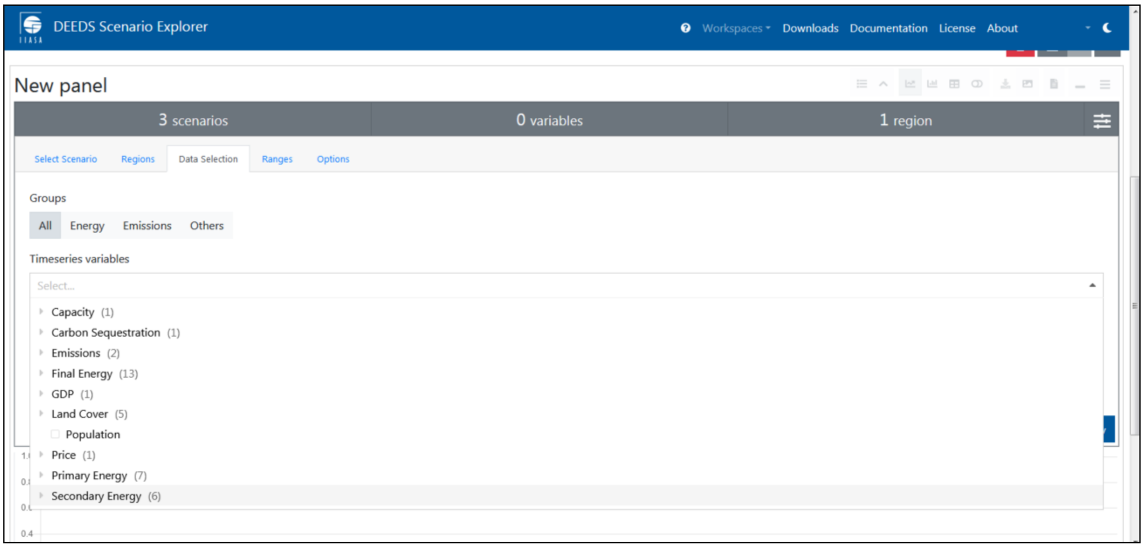


Figure 5 Creation of a new panel. Selection of variables

The user may then choose how the data should be displayed. The default is set to line plots, but bar plots and tables may also be selected. In addition, the time range and the scales may be arranged according to the needs of the user.

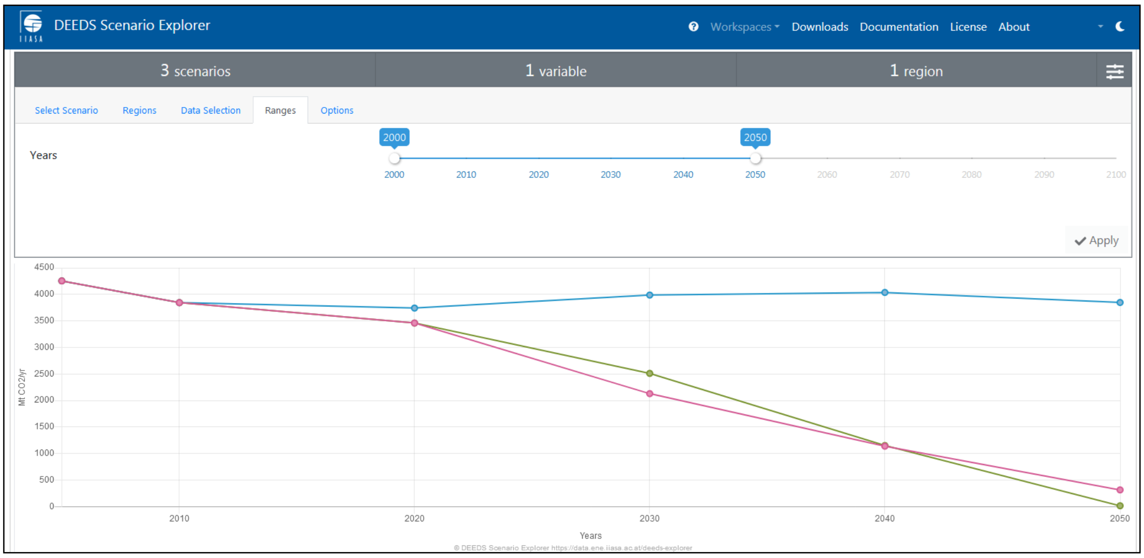


Figure 6 Selection of the range

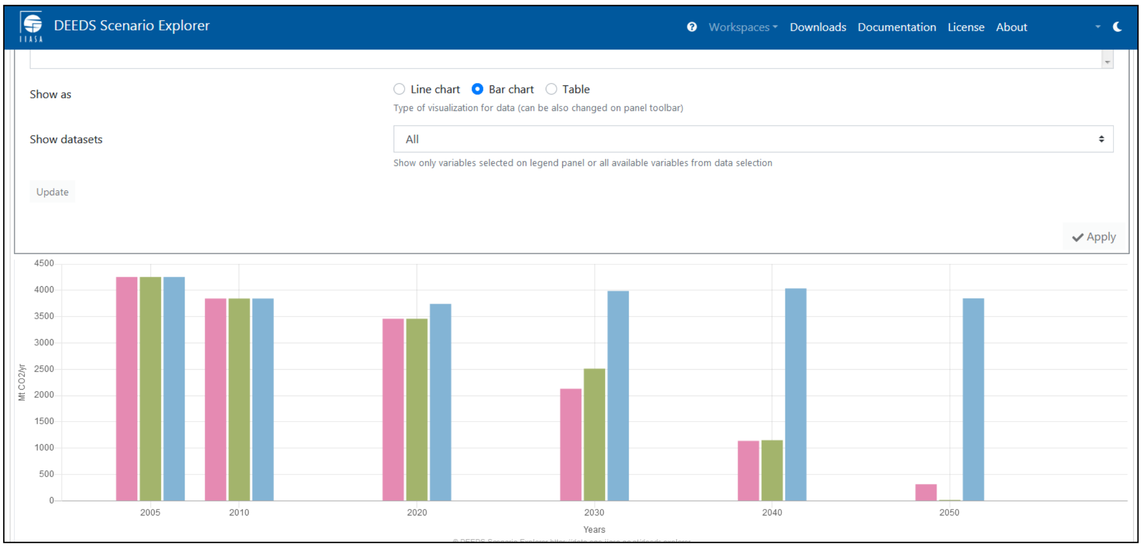


Figure 7 Bar chart display

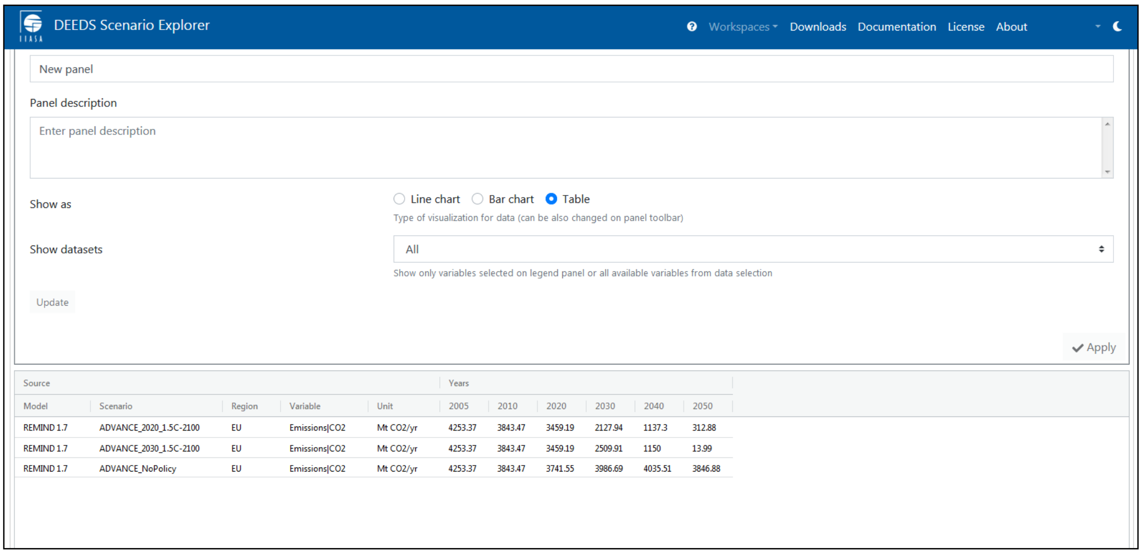


Figure 8 Table display

Additionally to plots and tables, text panels may be included into workspaces. These are especially helpful to comment the analysis that has been done.

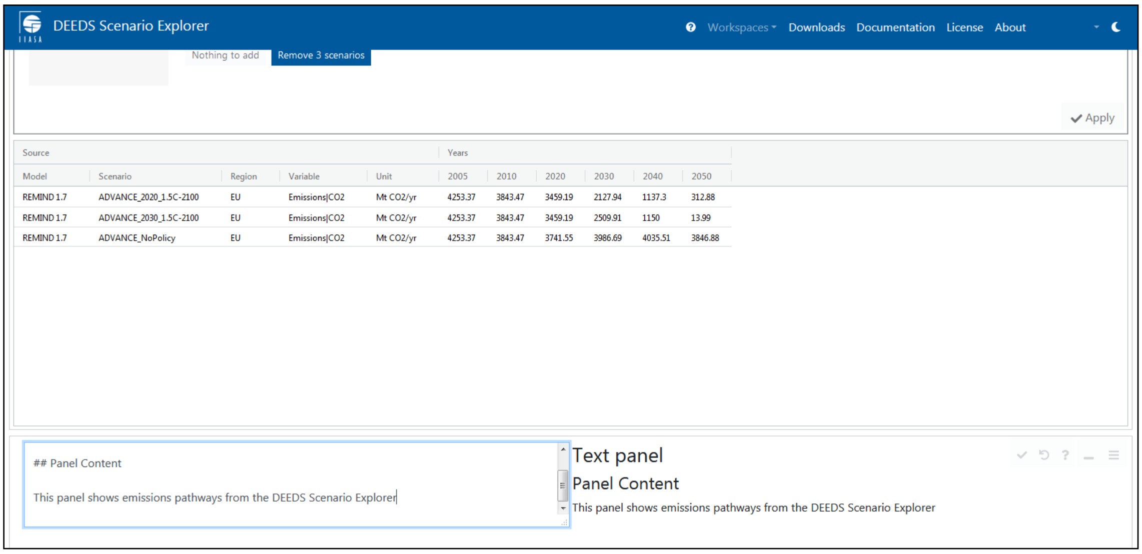


Figure 9 Addition of a text panel

The ensemble of panels can be accessed from the workspace overview. The data from the plots and tables may also be downloaded.

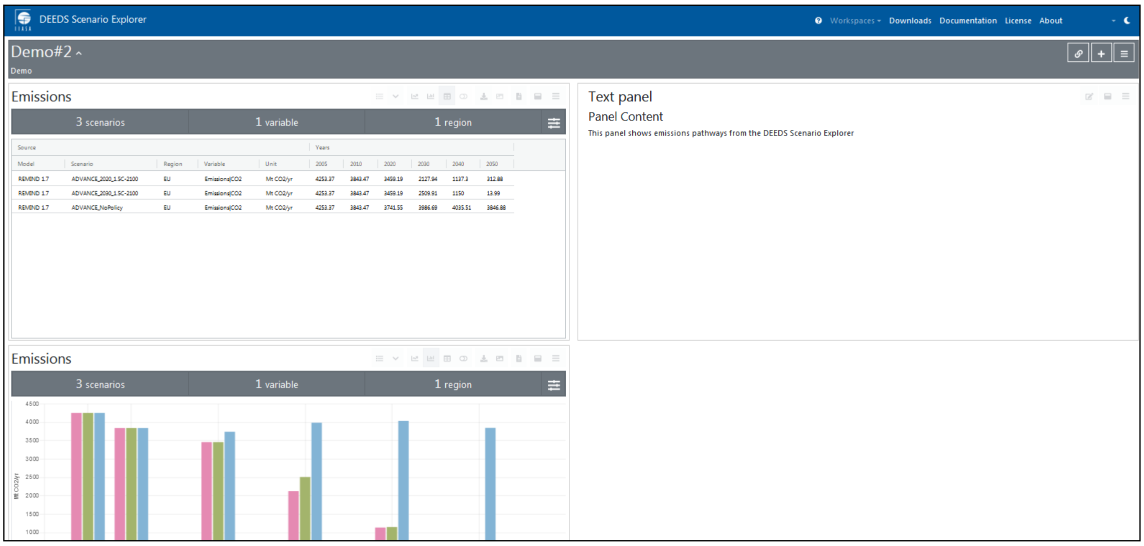


Figure 10 Workspace overview

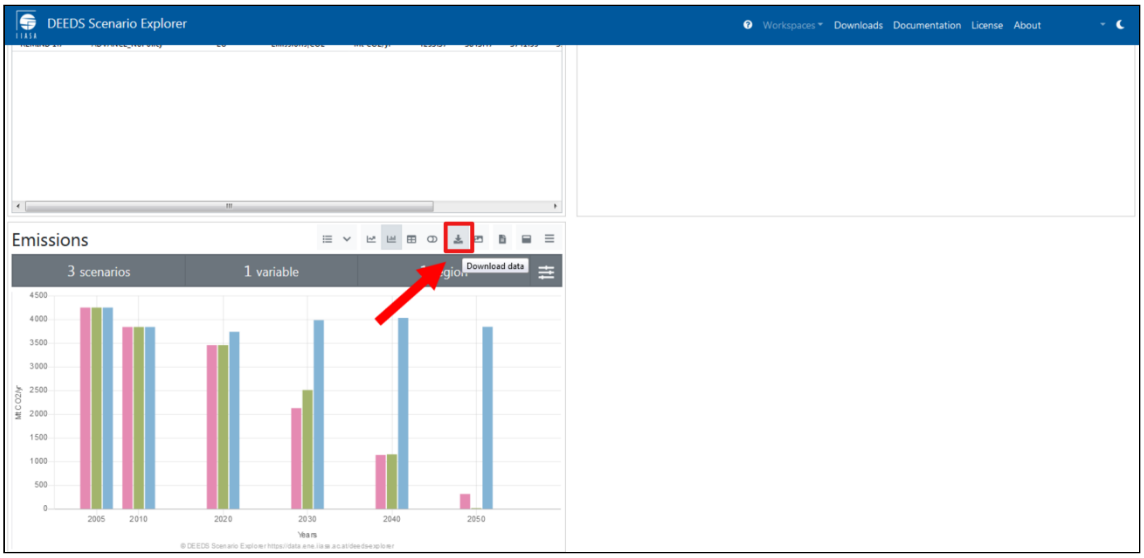


Figure 11 Download of data

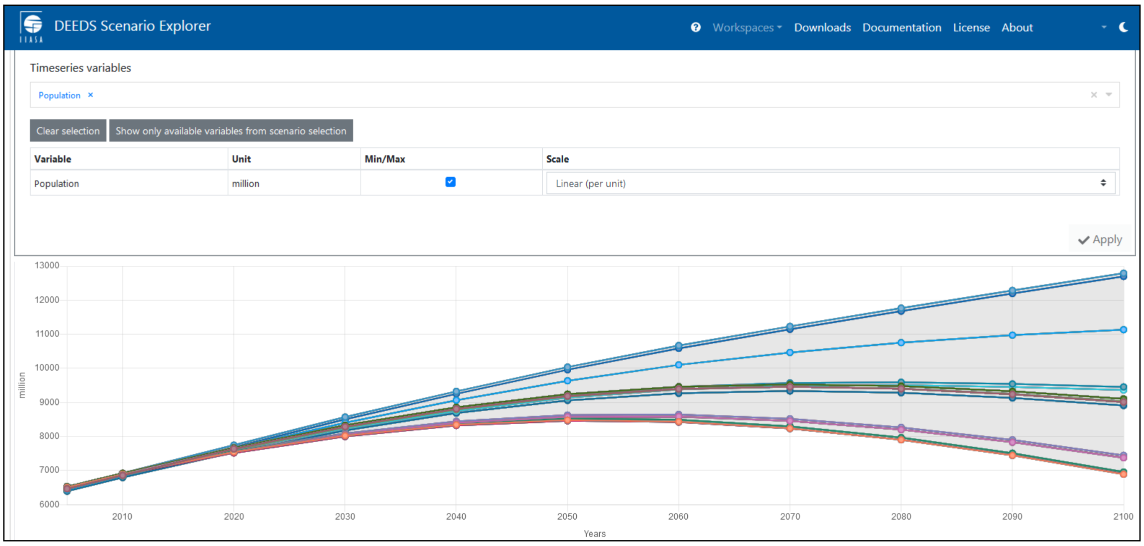


Figure 12 Example of a line plot, here for population dynamics

2 The Technology database

The DEEDS "Technology database" (available on the DEEDS website https://deeds.eu/results/) consists of two main elements, both covering technology options for decarbonizing the economy of the EU within the next decades:

1. Spreadsheets with "Raw data and information", to be provided for download as .xls files on the DEEDS website
2. "Fact sheets" summarizing the content of these spreadsheets on an aggregated level, to be provided for download as pdf files (in an appropriate format for prints) on the DEEDS website. Additionally, the Factsheets also provide an introduction providing a perspective of the context and current status of the sector in the context of decarbonization and a discussion on the future potential of each of the technologies.

All decarbonization technologies and options are categorized into one of the following sectors:

1. Industry
2. Mobility
3. Power generation
4. Residential sector

Industry is subdivided into:

- Aluminum
- Ammonia
- Cement
- Ceramics
- Copper
- Ethylene and other olefins
- Glass
- Hydrogen, methanol and synfuels
- Iron and steel
- Lime
- Nitric acid and other chemicals
- Others
- Pulp and paper
- Refineries

Mobility is subdivided into:

- Aviation
- Passenger vehicles
- Rail
- Shipping
- Trucks and buses

Power generation is subdivided into:

- Non-combustible renewables and Nuclear power
- Fossil and combustible renewable power

The residential sector is divided into:

- Heating, ventilation and air conditioning

- Lighting and appliances
- Passive means

The fact sheets (examples shown in Figure 13 - Figure 16) as well as the spreadsheets contain brief general overviews of each sector and its subdivision and more specific data and information regarding each of the identified technology options for decarbonisation. The relevance of each (sub)sector in terms of contribution to the overall EU greenhouse gas emissions is visualized in the fact sheets. The spreadsheets contain the complete list of data sources used for establishing both spreadsheets and fact sheets, while the fact sheets only list the main references.

The type of information and data provided is not entirely uniform among sectors, subsectors and measures due to inhomogeneous data availability. Whenever possible, i.e. in case of available data, investment and operation costs as well as levelized product or service costs are quantified for individual decarbonisation technologies between today and 2050. Technology Readiness Levels (TRL) and potential market entries are also covered, as well as potential reductions of energy/electricity/heat demand and CO_2/GHG emissions.

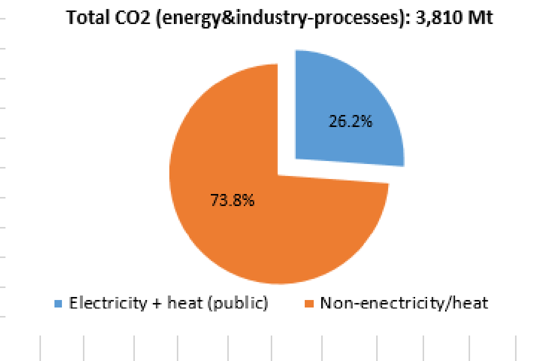
In addition, results from selected, recent and relevant studies are shown (examples in Figure 17 and Figure 18).

Power Generation - Non-combustible Renewables and Nuclear

Introduction

The EU is aiming to cut emissions by 80-95% below 1990 levels by 2050. To achieve this goal, the power sector needs to be decarbonised with upgrading and phasing out fossil power plants and installation of renewable and/or nuclear power generation. In 2017, the structure of installed electrical capacity of combustible fuels in the EU-28 was equal to 45%, while the share of hydro was at 15%, nuclear at 12%, wind at 17% and solar at 11%. The remaing technologies like geothermal, tide and wave were negligible. Total gross electricity production in the EU-28 was 3,294 TWh in 2017, with the highest share of electricity produced from renewable sources (31%), nuclear power plants (25%), gas fired power plants (22%) and coal fired power plants (20%). Additionally, EU-28 total gross production of heat in 2017 was 670 TWh. The highest share of heat was produced from natural gas and manufactured gases (39%), followed by renewable energy carriers (27%) and solid fossil fuels (23%).

CO2 emissions of EU electricity and heat sector (2017)



Discussion: Substituting coal and gas power plants by renewables and/or nuclear power is an effective decarbonization strategy, since direct GHG emissions of renewables are usually zero or low; taking into account indirect (i.e. those due to e.g., production, transport and disposal based on the entire life cycle) GHG emissions of renewable and nuclear power plants, these technologies can still be categorized as "low-carbon": hydro, wind and nuclear power exhibit the lowest life-cycle GHG emissions in the order of 5-30 g/kWh; solar PV, CSP, marine and geothermal generation can cause life cycle GHG emissions of up to 100 g/kWh. Wind (on- and offshore) power and solar PV (roof-top and open-ground) exhibit the largest generation potentials within the EU and their Levelized Costs of Electricity (LCOE) are sometimes already competitive with low-cost fossil generation. Further cost decreases are expected in the future. However, both technologies require additional measures and/or technologies in order to guarantee stable supply due to their intermittent nature - these include electricity storage, demand side management, additional power transmission and distribution, etc. Hydro, nuclear and geothermal power can provide baseload generation; however, their potentials for additional generation is - due to different reasons - lower and expected future cost reductions are also modest.

Technology	CAPEX (€/kW) *				OPEX (FOM (€/kW*a) & VOM (€/MWh)) *								Comments
	2020	2030	2040	2050	2020		2030		2040		2050		
					FOM	VOM	FOM	VOM	FOM	VOM	FOM	VOM	
Wind Onshore													
Wind onshore large scale	1200-1400	990-1260	840-1110	780-1040	13-22	0.15-0.25	13-21	0.15-0.25	13-21	0.15-0.25	12-20	0.15-0.25	LCOE are expected to decrease from 6-8 €cents/kWh today to 4-7 €cents/kWh in 2050.
Wind small scale rooftop	2850	1850	1750	1650	25	0.1	21	0.1	18	0.1	17	0.1	Niche technology

* numbers are rounded

Figure 13 Example of a technology fact sheet, page 1 of "Power generation – Non-combustible Renewable and Nuclear"

Power Generation - Non-combustible Renewables and Nuclear

Wind Offshore													
Wind offshore	2220-3210	1800-2450	1760-2300	1750-2240	33-48	0.39	27-37	0.39	26-35	0.39	26-34	0.39	LCOE are expected to decrease from 10-18 €cents/kWh today to 6-10 €cents/kWh in 2050.
Wind offshore - remote	3700	2850	2700	2650	55	0.39	43	0.39	40	0.39	39	0.39	
Solar													
Solar PV large scale	690-720	630-690	460-570	410-500	13-22	0	11-15	0	10-13	0	9-11	0	LCOE are expected to decrease from 6-22 €cents/kWh today to 3-10 €cents/kWh in 2050.
Solar PV small scale rooftop	1430	930	750	610	24	0	17	0	15	0	13	0	
Concentrating Solar Power (with storage)	5500	4240	3440	3080	121	0.1	113	0.1	99	0.1	77	0.1	LCOE are expected to decrease from 11-27 €cents/kWh today to 6-9 €cents/kWh in 2050.
Hydro													
Reservoir	3000	3000	3000	3000	26	0.3	26	0.3	26	0.3	26	0.3	LCOE are in the range of 3-15 €cents/kWh today and expected to remain in the same range in the future.
Run of River	2450	2400	2350	2300	8.9	0	8.2	0	8.2	0	8.1	0	
Other renewables													
Geothermal	3900-5000	3200-4600	2900-3700	2600-3300	90-95	0.3	90-95	0.3	92-100	0.3	90-105	0.3	LCOE are in the range of 6-15 €cents/kWh today and expected to remain in the same range in the future. Potential heat credits are impotant.
Tidal and waves	6100	3100	2030	1980	40	0.1	33	0.1	28	0.1	24	0.1	LCOE are expected to decrease from 15-40 €cents/kWh today to 10-20 €cents/kWh in 2050.
Nuclear													
Nuclear III generation	5300-6000	5000-6000	4750-6000	4700-6000	120	6.4	115	7.4	108	7.6	105	7.8	LCOE are in the range of 5-12 €cents/kWh today and expected to remain in the same range in the future.

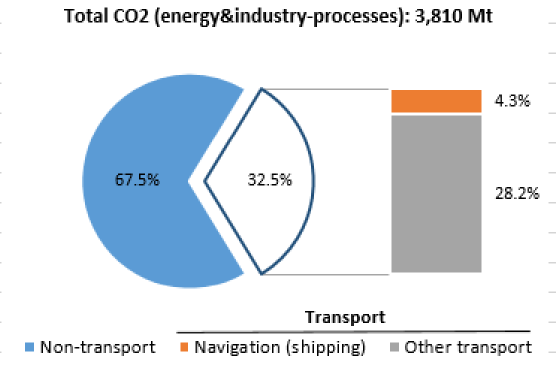
Page 2

Figure 14 Example of a technology fact sheet, page 2 of "Power generation – Non-combustible Renewable and Nuclear"

Mobility - Shipping

Introduction	CO2 emissions of EU transportation sector (2017)

Shipping is one of the largest greenhouse gas emitting sectors of the global economy, responsible for ca. 1 Gt of CO2eq every year. EU related shipping is responsible for about 20% of global ship GHG emissions. It is now generally accepted that ship design efficiency requirements, while potentially having an important impact on future emissions growth, will fall well short of what is needed in terms of emission reduction. Further operational efficiency measures, e.g. capping operational speed, will be important to immediately peak energy consumption and emissions, but will be insufficient to decarbonise the sector or reduce its energy needs. In this context, with all the likely immediate measures adopted, energy demand for EU related shipping is still expected to grow by 50% by 2050 over 2010 levels. The complete decarbonisation of EU-related shipping in 2050 via e-fuels would require 11-53% additional renewable electricity generation across the EU28 over the 2015 levels. This range is estimated on the assumption that EU maritime emissions will grow by around 50% between 2010 and 2050, taking into account the deployment of a range of short & mid-term measures, energy efficient design, speed reduction and wind propulsion.



Technology	Investment cost	Operational cost	Emissions	Energy cons.	Notes
Standard					
Internal Combustion Engine Ships	ICE 425 €/kW	MGO 573 €/t MGOeq. IFO 398 €/t MGOeq. MGO case (costs given in Mio €/year*): Fuel 3.0 Engine 0.4 Crew 2.5 Payload 555 €/ton/a 202 €/m3/a	3.4 kgCO2/kg MGO 3.3 kgCO2/kg MGOeq HFO	1715 MJ/km	Heavy fuel oil (HFO - 72% use) Marine gas/diesel oils (MGO/MDO - 28% use) (IFO - intermediate fuel oil) *Assumptions: linear depreciation and cost of capital at 7%, ship capacity 1'380 TEU, main engine 14'280 kW, consumption 21.3 tons HFO at 16 knots, 30 years lifetime, 250 days in operation per year.
Innovative Techniques/ Alternative Fuels					
Low-carbon fossil fuels	ICE 425 €/kW	LPG 860 €/t MGOeq. LNG 510 €/t MGOeq. Methanol 620 €/t MGOeq. Payload 555 €/ton/a 202 €/m3/a	Reduction by max. 20-30% vs. conventional fuels 2.8 kgCO2/kg MGOeq LNG	1715 MJ/km	Fossil fuels with a lower carbon footprint than conventional fossil fuels (e.g. LPG, LNG, Methanol)

Page 1

Figure 15 Example of a technology fact sheet, page 1 of Mobility – Shipping"

Mobility - Shipping

Carbon-neutral hydrocarbon fuels: Electro-methane ICE and electro-methanol	ICE 425 €/kW	e-Methane 780 €/t MGOeq. e-Methanol 708 €/t MGOeq. Payload 555 €/ton/a 202 €/m3/a	Almost carbon neutral if produced with renewable energy and CO2 captured from air	Expended energy for e-methane (2018) 2.6 MJ/MJ (2050) 2.1 MJ/MJ	Energy storage: synthetic methane from electricity Energy transformation: direct combustion of e-methane in ICE. Electro-methane, to be subsequently liquefied, can be synthesised using the methanation chemical process to combine hydrogen (H2) from electrolysis with carbon dioxide (CO2) to produce methane (CH4). Synthetic diesel and synthetic methane pathways place the highest demands on renewable energy supplies due to the high amounts of electricity needed for electrolysis.
Carbon-neutral hydrocarbon fuels: Electro-diesel ICE	ICE 425 €/kW	no data for production costs Payload 555 €/ton/a 202 €/m3/a	Almost carbon neutral if produced with renewable energy and CO2 captured from air	Expended energy for e-diesel (2018) 3.3 MJ/MJ (2050) 2.67 MJ/MJ	Energy storage: synthetic diesel from electricity Energy transformation: Direct combustion of electro-diesel in ICE Diesel fuel can also be synthetically produced using renewable hydrogen from electrolysis and CO2 capture from air. The resulting fuel is still carbon-based, hence its combustion emits CO2 (and NOx); but since the CO2 is originally captured from the atmosphere, such a synthetic diesel fuel would be carbon neutral on a full life cycle basis provided the energy/electricity used for electrolysis and fuel synthesis was carbon free.
Zero-carbon fuels: Hydrogen Fuel Cell (PEM FC) - Electric Ships	Tank 5.3 €/kWh PEM 1780 €/kW (2020, 10 years lifetime) PEM 425 €/kW (future, 15 years lifetime)	Costs given in Mio €/year*: Fuel 3.8 Storage 2.7 Engine 0.8 Crew 1.3 Green H2 485 €/t MGOeq. Blue H2 350 €/t MGOeq. Grey H2 302 €/t MGOeq. Payload 555 €/ton/a 202 €/m3/a	Climate neutral on a tank-to-wake basis (H2 fuel cells are not causing any emissions apart from water) 10.7 kgCO2/kg H2 (grey) 0.2 kgCO2/kg H2 (green) 2.5 kgCO2/kg MGOeq H2 (grey) 0.1 kgCO2/kg MGOeq H2 (green)	1487 MJ/km (2019) 1770 MJ/km (2050) Expended energy for liquid H2FC (2050) 1.72 MJ/MJ	Energy storage: liquid H2 Energy transformation: electrochemical via fuel-cells This technology converts energy stored in fuels (e.g. liquid hydrogen) directly to electricity via an electrochemical process in fuel-cells, which in turn powers electric motors. *Assumptions: linear depreciation and cost of capital at 7%, ship capacity 1'380 TEU, main engine 14'280 kW, consumption 21.3 tons HFO per day at 16 knots, 30 years lifetime, 250 days in operation per year. Grey H2: from Natural gas Blue H2: from Natural gas with CCS Green H2: from electrolysis using renewable electricity

Page 2

Figure 16 Example of a technology fact sheet, page 2 of "Mobility – Shipping"

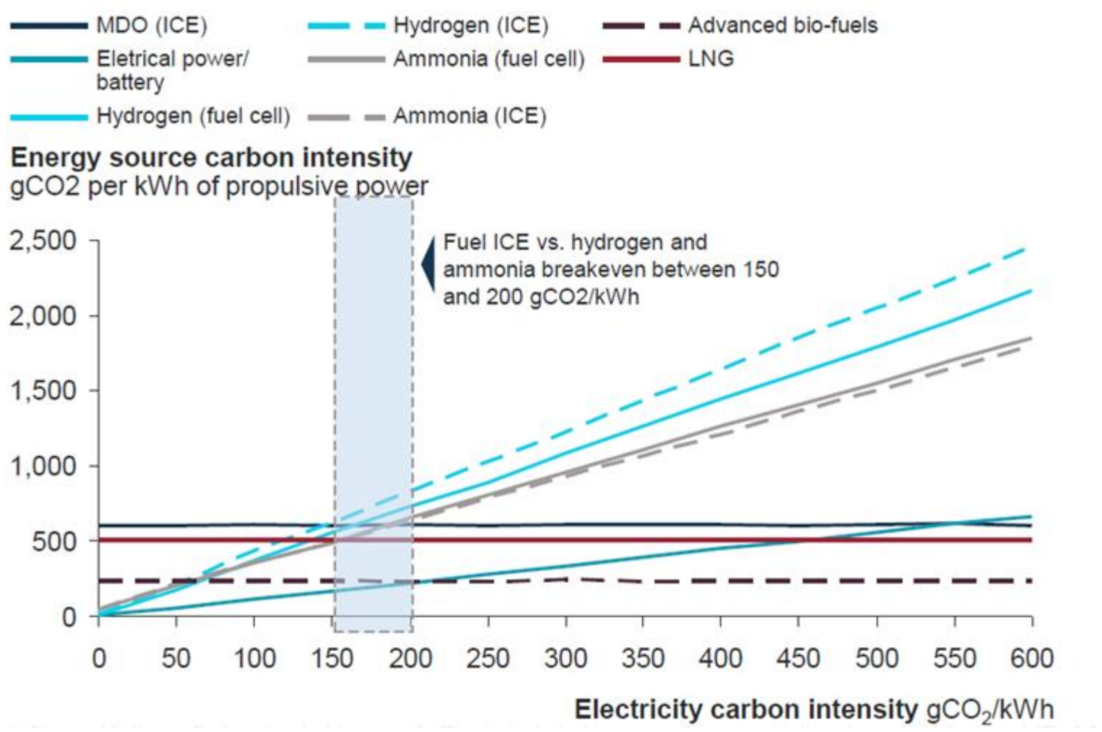


Figure 17 Greenhouse gas emissions of different traditional and advanced (low-carbon) fuels for shipping. Source: Amplifier, ETH Zurich Sustainability in Business Lab (2019). Deep-dive: Comparison of zero-carbon fuels. Towards net-zero.

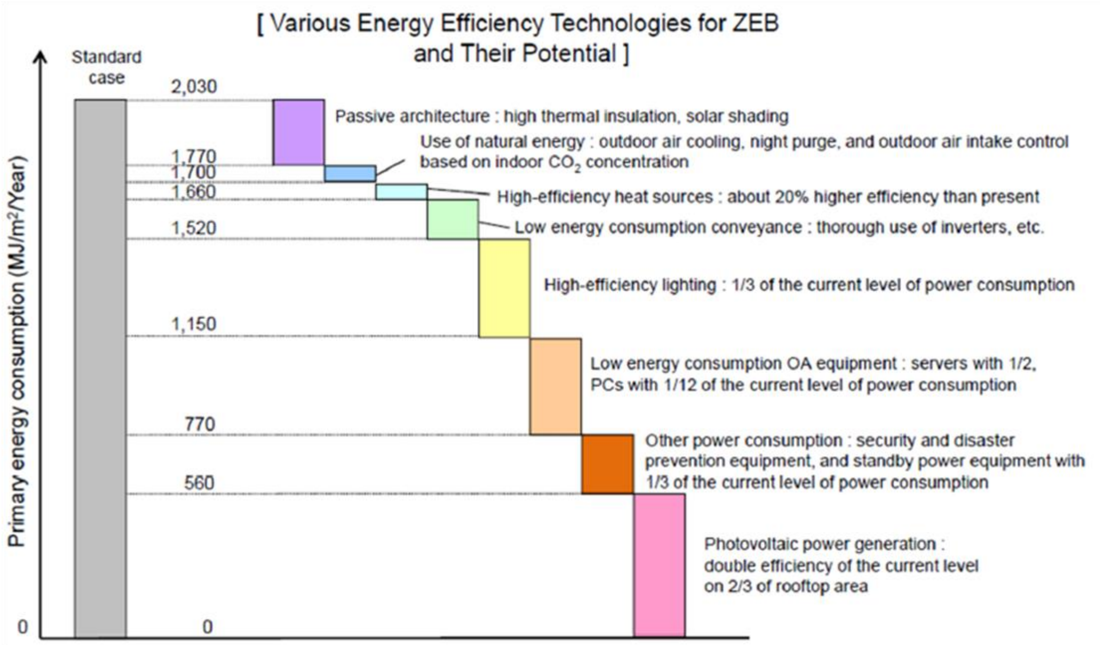


Figure 18 Example of technical measures to achieve net-zero energy buildings. Source: APEC Energy Working Group (2018). APEC Nearly (Net) Zero Energy idling Roadmap.