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under the aspects of flexibility and technological progress

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D1.1 Qualitative description of the scenario storylines

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Executive Summary

This document has the objective to present the draft qualitative description of the scenario storylines for the REFLEX project.

This scenario description provides the overall qualitative framework for the modelling activities in all other Work Packages by setting-up two holistic socio-technical scenarios based on different scenario storylines. That includes the definition of the main framework parameters and a draft of the societal and political environment.

Based on these qualitative scenario storylines the main macro-economic and societal drivers (e.g. GDP and population) as well as techno-economic parameters have been determined and quantified in the next working steps of Work Package 1.

This qualitative scenario description is intended for the project officer and all project partners, their project managers and project teams.

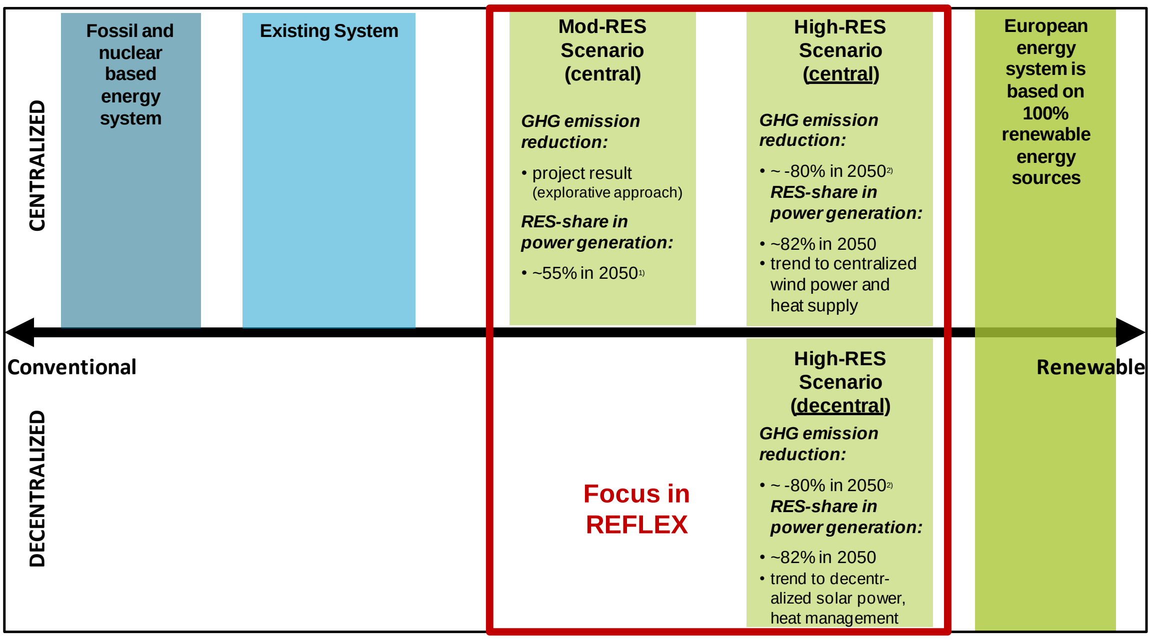
1. General drivers and definition of the scenarios

In this section the overall philosophy and definition of the two REFLEX-scenarios is described. Sector-specific policy-scenario assumptions are specified in more detail in section 3.

In the REFLEX-project two different main scenarios are distinguished: a more or less “reference” scenario based on observed trends and most recent projections and an ambitious policy scenario representing an ambitious decarbonisation pathway for Europe to 2050.

- **Moderate renewable scenario (Mod-RES):** Framework conditions will be based on PRIMES 2016 Reference scenario (Capros et al. 2016). It is defined to reflect the development of electricity demand taking into account past dynamics but also the future developments regarding current economic development and energy policies[1]. Present policy targets and actions which have been already decided or implemented will be reflected in Mod-RES. This is not necessarily the most likely or the most probable future development, but rather serves as a projection to which the policy scenario with ambitious decarbonisation pathway is compared to (Figure 1).
- **High renewable scenario (High-RES):** Framework conditions are similar to those of Mod-RES in terms of population and economic growth, while energy prices and CO_2 prices are assumed to be higher. Furthermore, more ambitious climate policies are considered in this scenario. One major target of the scenario will be to limit global temperature increase to 2°C, by more drastically reducing GHG emissions and achieving the EU 2020 energy saving target in the short term. Higher contribution from learning curves and need for flexibility options due to a large share of intermitting renewable energy. To capture the different possible stances on a future energy system without differentiating too much, two versions of the *High renewable, high flexibility scenario (High-RES)* are developed within REFLEX: the “centralized” case and the “decentralized” case. Major differences of these two cases concern the amount of decentralized technologies. This includes both the generation and supply side in the sectors electricity, heat and transport (Figure 1).

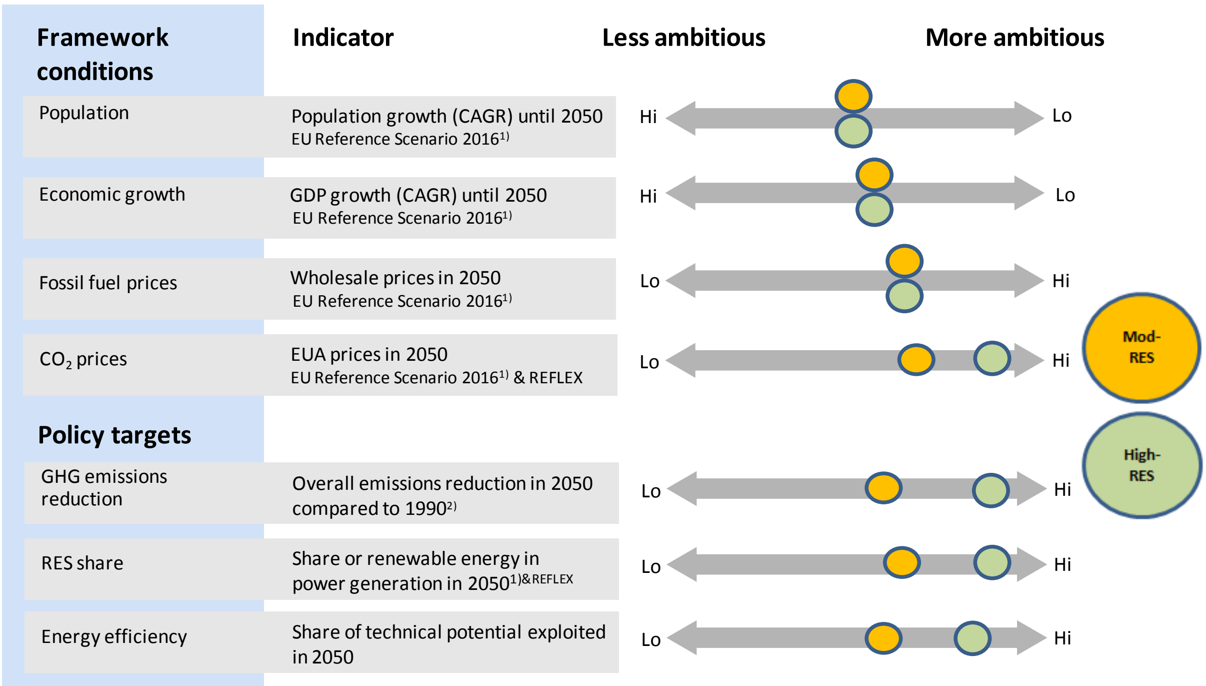
[1] potential cut-off date: end of 2015/2016.



1) EU Reference Scenario 2016 (Capros et al. 2016) 2) EC Roadmap for moving to a competitive low carbon economy in 2050 (COM 2011/0112)

Figure 1: **REFLEX scenario positions in the energy system**

Overall differences occur between scenarios, both at European and country level. The main definitions of framework conditions and policy targets for the REFLEX scenarios are shown in Figure 2.



1) EU Reference Scenario 2016 (Capros et al. 2016) 2) EC Roadmap for moving to a competitive low carbon economy in 2050 (COM 2011/0112)

Figure 2: **Definition of REFLEX framework conditions Mod-RES compared to High-RES scenarios (Hi = High, Lo = Low)**

Table 1: General model drivers provided by EU Reference Scenario 2016 (Capros et al. 2016)

Indicator	Unit	Source	used in REFLEX Scenario	Category
Gross domestic product	in 000 Meuro'13	EU Reference Scenario 2016	Mod-RES & High-RES	country data
Population	(million)	EU Reference Scenario 2016	Mod-RES & High-RES	country data
Gross value added industry	in 000 Meuro'13	EU Reference Scenario 2016	Mod-RES & High-RES	country data
Gross value added industry by subsector	in 000 Meuro'13	EU Reference Scenario 2016	Mod-RES & High-RES	country data
Gross value added tertiary	in 000 Meuro'13	EU Reference Scenario 2016	Mod-RES & High-RES	country data
Gross value added tertiary by subsector	in 000 Meuro'13	EU Reference Scenario 2016	Mod-RES & High-RES	country data
Number of households	mio	EU Reference Scenario 2016	Mod-RES & High-RES	country data
Household size	inhab/ household	EU Reference Scenario 2016	Mod-RES & High-RES	country data
Passenger transport activity by country and mode	Gpkm	EU Reference Scenario 2016	Mod-RES & High-RES	country data
Freight transport activity by country and mode	Gtkm	EU Reference Scenario 2016	Mod-RES & High-RES	country data
Gas wholesale price	in €'13 per boe	EU Reference Scenario 2016	Mod-RES	global data
Electricity wholesale price	in €'13/MWh	EU Reference Scenario 2016	Mod-RES	country data
Oil wholesale price	in €'13 per boe	EU Reference Scenario 2016	Mod-RES	global data
Coal wholesale price	in €'13 per boe	EU Reference Scenario 2016	Mod-RES	global data
Carbon value - ETS sectors	in €'13/ t of CO2	EU Reference Scenario 2016	Mod-RES	global data
Carbon value - non-ETS sectors	in €'13/ t of CO2	EU Reference Scenario 2016	Mod-RES	global data
Non fossil fuels in electricity generation (%)2	%	EU Reference Scenario 2016	Mod-RES	country data
Resource fuel price and fuel taxation (by fuel type[3])	€'13/MWh, €'13/litre, €'13/kg	Eurostat/ EC Directorate-General Taxation and Customs Union[4]/ tbd[5]	Mod-RES	country data
Transport fuel consumption by country and fuel	TWh	EU Reference Scenario 2016	Mod-RES	country data
Car vehicle stock	mio	EVI(2016) / national statistics/ tbd	Mod-RES	country data/global data
Truck vehicle stock	mio	EU Reference Scenario	Mod-RES	country data

2 Renewable energy forms and industrial waste

3 Gasoline, diesel, bioethanol, biodiesel, LPG, hydrogen, CNG

4 Current values

5 tbd = to be defined

		2016		
Bus vehicle stock	mio	EU Reference Scenario 2016	Mod-RES	country data
Train vehicle stock	mio	EU Reference Scenario 2016	Mod-RES	country data
CCS permitted	yes or no	-		EU data

Source: own list, Capros et al. 2016

Assumptions regarding general drivers will be based on the latest EU Reference Scenario 2016 provided by the European Commission (Capros et al. 2016) and integrated into the overall modelling platform provided by ESA[2]. This scenario includes wholesale prices for major energy carriers, GDP, gross value added, population, the number of households and CO_2-certificate prices (Table 1).

In both REFLEX scenarios identical GDP and population projections have been chosen as calculation basis (see Figure 2) to ensure an undistorted analysis of policy options, their interaction and optimal portfolio and their impact on environment and society.

In addition to the above mentioned general model drivers provided by the EU Reference Scenario 2016, more specific information will be needed as shown in Table 2. If available this information will be used from EU Reference Scenario 2016. If this information cannot be provided by the EU Reference Scenario 2016 than additional external sources, own model results (e.g. employment) or own estimations will be used.

Table 2: Model drivers to be defined

Indicator	Unit	Source	Category
Employment Industry	in 000 persons	tbd	country data
Employment Industry by subsector	in 000 persons	tbd	country data
Employment Tertiary	in 000 persons	tbd	country data
Employment Tertiary by subsector	in 000 persons	tbd	country data
Living area per dwelling	m^2/dwelling[6]	tbd	country data
Uranium wholesale price	€'13/MWh	tbd	global data
Lignite wholesale price	€'13/MWh	tbd	global data

6 Either an average value or distinguished by type of dwelling (e.g. single-family-dwelling vs. multi-family-dwelling)

2. SOCIO-TECHNICAL FRAMEWORK FOR THE MOD-RES SCENARIO AND THE HIGH-RES SCENARIO

The aim of the sociotechnical scenario descriptions here is to provide a qualitative account of the potential future social, economic, political and technological drivers that are coherent with the REFLEX quantitative scenarios. The scenario descriptions make use of the large body of previous work that have developed future scenarios from this perspective (Bernstein et al., 2008; Pachauri et al., 2014; UNEP, 2002, 2007, 2012; van Vuuren, Kok, Girod, Lucas, & de Vries, 2012; Watson & Albritton, 2001). In particular the REFLEX sociotechnical scenarios use the Global Environmental Outlook 4 (GEO-4) scenarios as a starting point. This is because these scenarios were developed in consultation with governments and other organizations across the globe and because the GEO-4 scenarios reflect differences in key drivers that the REFLEX scenarios also aim to reflect.

2.1. MOD-RES SCENARIO – SOCIO-TECHNICAL DESCRIPTION

The primary assumption of the Mod-RES scenario is that no policy measures are introduced beyond those that have been decided or already implemented. Therefore the Mod-RES scenario emphasizes the continuation of existing policies on climate change mitigation, innovation, value systems and economic growth. More specific descriptions are shown in Table 3 below.

More specifically, the Mod-RES scenario assumes that the current balance between the government and private sector is maintained in the future, and free trade remains a prime goal of international cooperation. The maintenance of the status quo is evidenced in the continued role of private institutions in education, healthcare and research and development aid. Meanwhile, as a reference scenario, only existing international agreements and policies are in place to mitigate environmental degradation and climate change. Since no new policy measures are assumed, there is a little emphasis in this scenario on social development beyond the status quo either. Public participation in government is relatively low, governmental North-South development assistance is unchanged and no further action is taken to develop cultural understanding and diversity. Markets are open to international trade, and there is little regulation to ensure just employment conditions. Personal values are individually focused and individual resource demands follow historical trends related to economic output. The sociotechnical context of Mod-RES is based on the assumptions of the ‘Market First’ scenario in GEO-4 (UNEP, 2007) where adjustments have been made so as to better represent a business-as-usual reference where no further policy measures are implemented.

2.2. HIGH-RES SCENARIO – SOCIO-TECHNICAL DESCRIPTIONS

The High-RES scenario assumes a strong policy commitment to achieving societal goals for climate change mitigation, as well as other societal social and economic goals. A key background descriptor for this scenario is that global governments become sufficiently aware of the myriad social and environmental challenges facing society to implement policy to yield improvements in these areas. Economic growth is maintained at the same level as the reference scenario, but in High-RES scenario it is always considered simultaneously with environmental and social impacts. Thus this scenario differs from Mod-RES firstly in terms of increased role for government in general and cooperation on environmental and social issues. In High-RES scenario there is increased public spending worldwide on health and education, and increased North-South development assistance. In light of this cooperation, international institutions such as the EU and UN increase in importance and new ones emerge. Technological innovation still has a strong market focus, though there is a larger role for government engagement, and innovation focuses as much on reduction of environmental impact as on economic efficiency. Trade between nations is encouraged, but requirements for fair trade are emphasized. Considering societal values, there is little overt action on the issue of cultural understanding and diversity. Nevertheless, public participation in governance is generally higher. Personal values are in general more community-inclined than in Mod-RES scenario, though individual resource demands still follow historical trends related to economic output. The sociotechnical context of High-RES is based on the assumptions of the ‚Policy First' scenario in GEO-4 (UNEP, 2007).

Table 3: Socio-technical scenario descriptions

Driver category	Critical uncertainty	Potential scenarios	
		Mod-RES (adjusted from 'Markets First' in UNEP (2007)) (UNEP, 2007) (UNEP, 2007) (UNEP, 2007)	**High-RES,** sustainability (adjusted from 'Policy First' in UNEP (2007))
Institutional and socio-political frameworks	Dominant scale of decision making	International	International
	General nature and level of international cooperation	Increased cooperation based on economic issues	High cooperation relating to economic, social and environmental issues
	General nature and level of participation in governance	Low, following current trend	Medium
	Power balance between government and private and civil sector actors	No shift from current state, with strong private actors	More government than REFLEX reference and the current situation
	Level and distribution of government investment across areas (e.g. health, education, military and R and D)?	Medium and even distribution	Higher funding and higher for health and education
	General nature and level of official development assistance	No change from current	Higher, as grants and connected to climate mitigation policies
	Mainstreaming of social and environmental policies	No climate policy beyond that already in place in each geographical region, new policies are reactive to events	Strict climate mitigation policy to achieve international targets (e.g. 2 °C), elsewhere proactive policies on e.g. local air pollutants
Demographics	Actions taken related to international migration?	International migration as before	Medium
	Number of children women want to have when the choice is theirs to make	Trend towards fewer births as income rises	Trend towards fewer births as income rises based on proactive policies
Economic demand, markets and trade	Actions taken related to the openness of markets?	Move towards increased openness	Openness with some emphasis on fair trade principles
	Emphasis on sector specialization vs. diversification in the economy	Specialization	Balanced
	How much do people choose to work in the formal economy?	Most work in the formal economy	Most work in the formal economy
	General level and emphasis of government intervention in the economy	Government intervention to facilitate the functioning of efficient markets	High intervention considering both efficiency of markets and fairness
Scientific and	Levels, sources and emphases of R and D investment?	High investment, private or by government at behest of private	Government financed R and D with focus on profit

technological innovation		sector	
	Emphasis in terms of energy technologies?	Technologies developed to improve economic efficiency	Technologies developed to improve general efficiency and environmental impact
	Access and availability of new technologies	Dependent solely on the market	Promotion of technology transfer and diffusion
Value systems	Actions taken related to cultural diversity	No further action beyond those in place	No further action beyond those already in place
	Emphasis on individualism related to the community	Individual	Greater emphasis on community
	What are the key priorities with regard to protected areas?	Emphasis on tourism development and some genetic resource protection	Species conservation and ecosystem services including sustainable use and benefit sharing
	Shifts in resource demand independent of changing prices and income	Follow trends in meat consumption, energy, water and other resource use	Follow trends in meat consumption, energy, water and other resource use

Source: As noted driver categories, critical uncertainties and the description of the scenarios themselves are based on (though not entirely identical to) UNEP's GEO-4 scenarios UNEP (2007)

3. REFLEX Moderate renewable scenario

The **Moderate renewable scenario (Mod-RES)** shall consider targets and actions which have been decided or already implemented at European and national level. Relevant policies in this context will be:

- the Renewable Energy Directive, (Directive 2009/28/EG; CEU 2008)
- the Energy Efficiency Directive, (Directive 2012/27/EU)
- the Directive on Energy Performance of Buildings, (Directive 2010/31/EU)
- the Ecodesign Directive, (Directive 2009/125/EC)
- the Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles, (Directive 2009/30/EC)
- and the EU regulation on CO2 emission from new cars and vans. (Regulation (EU) No 333/2014; Regulation (EU) No 253/2014)

In addition, the **EU Emissions Trading Scheme** and the expected EUA price trajectory will be relevant for industry and the power sector.

Business-as-usual technological learning will take place in the Mod-RES Scenario. However, progress from learning effects as well as knowledge transfer will be less pronounced than in the High-RES Scenario.

Table 4: Development of current policies in the "Moderate renewable" scenario 7

N°	Measures/Regulations	Legislative	Implementation
1	Technology standards	Ecodesign Directive	MEPS for all lots for which regulations have been implemented before 29 February 2016
2	Energy efficiency standards for renovation	Directive on the energy performance of buildings	National building code requirements, 2015 or planned tightening as far as data available
3	Energy efficiency standards new buildings	Directive on the energy performance of buildings	National implementation of NZEB standards after 2018 (for public buildings) and 2020 (for all buildings).
4	RES obligation	Renewable energy directive	Current implementation in Member States (only for new buildings in few countries) Increased share of biofuels for all transport modes, Reduced biofuels taxation for transport use
5	Energy labelling	Energy labelling directive	Mandatory for new devices for appliances already included / initiated in 2016
6	EU Emission Allowances	Emission Trading Scheme	CO_2 price: increase to ~90 EUR/tCO_2-equ in 2050 (e.g. from EU Reference Scenario 2016 or model result) Transport sector: increase of cost (e.g. air mode)
7	Energy and CO_2 taxation	Energy Taxation Directive	Taxes varying by fuel and sector and by country (e.g. German RES Umlage)
8	Energy saving obligation	Energy Efficiency Directive	Current implementation in MS 1 to 1,5% p.a.
9	Fuel Quality	Fuel Quality Directive	CO_2 emission factor for fuels
10	Clean and Energy Efficient Road Transport Vehicles	Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles	Renewal of the road vehicle fleet (
11	CO_2 standard for new cars and vans	EU regulation on CO_2 emission from new cars and vans	Renewal and technology of cars and vans vehicle fleet
12	Aviation policies	Single European Sky II	Air non fuel cost, air access time to airport, air fuel consumption
13	Aviation policies on emissions	ICAO Chapters 3 (emissions)	Air emission factors
14	Maritime energy efficiency	IMO Energy Efficiency Design Index (EEDI)	Reduced ship fuel consumption factor

Source: Fraunhofer ISI, TEP, TRT

7 potential cut-off date: end of 2015/2016

4. REFLEX High renewable scenario

In the **High renewable (High-RES)** an overall **80% GHG emissions reduction in 2050** (compared to 1990) is intended, following the latest "Roadmap for moving to a competitive low carbon economy in 2050" of the European Commission (COM 2011/0112[8]). The overall achievement range has been defined as follows: -79 to -82% in 2050 compared to 1990 (COM, 2011/0112).

As milestone the main three European climate- and energy-policy targets for 2030 will be set:

- reducing greenhouse gas emissions by at least 40 % (compared to 1990);
- increasing the share of renewable energy sources to at least 27 %;
- increasing energy efficiency by at least 27 %.

In comparison to the existing Roadmap to a low carbon economy in COM (2011/0112), the High-RES Scenario will have a special focus on the influence and potential of flexibility mechanisms and learning curve effects of specific technologies (from economies of scale but also from additional investment in R&D and new technologies) in all sectors (e.g. electrolysis in industry or electric vehicle deployment targets in the transport sector).

In addition, methanation, water electrolysis for hydrogen production, methanol synthesis, Fischer-Tropsch-synthesis, etc. could be relevant for coupling of sectors in this context. However, the final composition of flexibility options and additional learning curve effects will by identified within the project and is, therefore, more a project result than a scenario assumption.

As discussed in chapter 1 a centralized and decentralized scenario case will be analysed having different sector perspectives of the future energy system (Table 5). In the electricity sector, the penetration of RES technologies differs between the centralized and decentralized case. In the centralized case, renewable power generation mainly takes place in large wind parks. While in the decentralized case renewable power generation is more regionally distributed using for example rooftop PV and distributed onshore wind plants. Heat supply will be managed on aggregated city levels in the centralized case while this changes in the decentralized case to building specific management. In the case of mobility lower costs and better infrastructure development will lead to higher numbers of electric vehicles and more vehicles-to-grid and postponed charging behaviour in the decentralized scenario case. The demand side will be more autarkic using more PV and storage, power-to-heat systems, micro CHP, solar thermal energy and heat pumps (see Table 5)

A more detailed description of the two scenario cases will be published soon in a policy brief.

8 http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0112

Table 5: Selected sector perspectives central vs. decentralized

Sector	Centralized	Decentralized
Power and Heat Supply	• Trend to large wind parks (on- & offshore), PV on open spaces • Heat supply managed on city level • Surplus power produces heat in centralized DH systems	• Trend to regionally distributed wind plants (onshore), PV on rooftops (and storage) • Heat supply managed on building level • Domestic space heating by decentralized DH systems and small-scale storages
Mobility	• BEV and PHEV price reductions are slow due to high battery prices • Basic charging infrastructure	• Battery costs decrease and selling price of BEV and PHEV drops • Well developed infrastructure of public and private charging points • Number of households generating the electricity (e.g. PV) that powers their EVs increases over time • Higher vehicles to grid and postponed charging
Demand	• Trend towards external supply	• Trend towards (semi-)autarky • Increasing share of PV and storage, Power-to-Heat, micro CHP, solar thermal energy, and heat pumps

Source: REFLEX

4.1. INDUSTRY SECTOR

The European Roadmap for moving to a competitive low carbon economy in 2050 has identified a target of -83 to -87% emission reductions in industry in 2050, which will also be set as target guideline in the “high renewable, high flexibility” scenario. (COM, 2011/0112)

Policy framework

Table 6 shows only selected possible policies to be considered in the scenario. However, to achieve an ambitious emission reductions target in industry of more than -83% other options, like for example new more efficient/alternative production technologies will have to make an important contribution. However, the exact composition of policies, technology portfolio and structural development will be a result of the project and not an ex-ante scenario assumption.

Table 6: Development of selected industry policies in the High-RES

N°	Measures/Regulations	Legislative	Implementation
1	Technology standards	Ecodesign Directive	Extension to additional lots and introduction of more ambitious standards for lots with existing regulation
3	EU Emission Allowances	Emission Trading Scheme	CO_2 price: increase to ~150 in EUR/ tCO_2-equ in 2050 Scope to remain as in phase 3
4	Energy and CO_2 taxation	Energy Taxation Directive	Tax is revised and will be based on CO_2 content following a similar price trajectory as the EU ETS in 2050. ETS is out of scope.
5	Energy saving obligation	Energy Efficiency Directive	Continuation of saving obligations beyond 2020.

Source: Fraunhofer ISI

Flexibility mechanisms and learning curve effects

It is expected that the policy scenario shows a higher need for flexibility than the reference scenario due to the larger share of fluctuating RES. The flexibility potential of industrial processes depends mainly on the electricity demand and the demand pattern of each process that may change in the future. Furthermore it is restricted by technical or economical constraints. It must be considered that the electricity demand of industrial production is directly linked to the demand of the output products. So it is necessary to estimate the long-term evolution of industrial production in order to derive the electricity demand. In the REFLEX project, two models will be used for determining the electricity system load curves on a national level. Based on appliance specific annual demand projections from the FORECAST model, the eLOAD model assesses the transformation of the load curve due to structural changes on the demand side and the introduction of new appliances by using hourly load profiles (http://www.forecast-model.eu). Analyzing the future shape of the load curve gives insights into the development of peak load, load levels and load ramp rates that are required for investment decisions about new electricity generation capacity and grid infrastructure. Apart from that, the models allow to analyze load flexibility, i.e. demand response (DR).

The results on DR potentials will be further refined within the framework of the project due to the research efforts related to technological learning curves and the results of the demand side management survey that will be conducted. In the industrial sector, the appliances contain amongst others different types of electrolysis, steel and pulp production, electric arc furnaces and cement mills. The integration of learning curves could focus on these appliances but also on demand control technologies, such as smart meters, building automation systems, DSM control infrastructure and other DSM technologies required for more flexibility in the electricity system. Considering the potential cost reduction of the technologies in the dissemination of flexible electricity consuming appliances allows determining the DR potential more thoroughly.

4.2. Tertiary sector & Residential sector

The European Roadmap for moving to a competitive low carbon economy in 2050 has identified a target of -88 to -91% emission reductions in buildings and services in 2050 (COM, 2011/0112), which will also be set as target guideline in the High-RES Scenario. In the building sector all new buildings from 2021 will be built to zero-energy-standards. The biggest challenge in the tertiary and residential sector will be the retrofitting of existing buildings and it's financing. In addition the use of renewable energy sources (also provided by district heating) and heat pumps/storage heaters will be pushed. (COM, 2011/0112)

Building technologies such as lighting, ventilation, cooling, heating, and others are most relevant contributors of energy consumption in commercial and public buildings. Likewise, building technologies are key to tap efficiency potentials in these kinds of buildings. A broad range of measures is needed to tap these potentials (as revealed by a study that involved various disciplines and technological areas throughout the Swiss building market about 150 different measures were identified, categorised, and characterised in terms of their technical performance and field of applicability).

Policy framework

Substitution effects towards non-renewable energy sources for space and water heating and various other kinds of measures in all technological areas contribute to efficiency improvement and GHG emission reduction: more efficient components and systems, controls, building automation, energy management and optimisation, add-on measures, and energy carrier substitution etc. Further, the installation of efficient systems should be coupled with their optimised usage to maximise energy savings.

Thus policy measures need to comprise all these thematic fields. Moreover it is emphasised that efficiency measures are available at all phases of a building's lifetime:

- conceptual design,
- planning,
- investment decision,
- installation,
- commissioning,
- and operation.

For each of these phases policy measures should address the following potential barriers and strengthen success factors:

- Access to capital: Barriers concerning the provision and management of financial resources including internal funds as well as external borrowing.
- Imperfect information: Barriers concerning asymmetries of information between different stakeholders (e.g. technology suppliers and procurers) lacks adequate information on the advantages of efficient heating and cooling technologies.
- Bounded rationality: Barriers concerning decision behaviour of individuals and organisation in the manner which is not assumed by economic models including personal attitudes, rule-of-thumb-approaches, and preferences
- Perceived and measured risks: Barriers concerning economic (price related), administrative, legal, organizational and technical risks which may occur when investing in heating and cooling technologies.
- Hidden costs: Barriers concerning overestimation of heating and cooling technology potentials such as costs for industrial production disruption, additional maintenance, training or gathering information.
- Split incentives: Economic incentives and interests often are different between investing parties (e.g. building owners, investment departments) und energy using parties (e.g. tenants, production departments in industrial firms) which may constitute a substantial barrier to the deployment of RES technologies.

The following table gives and overview and a selection of policy measures that address energy use of and in residential and tertiary buildings or both (first selection, draft):

Table 7: Development of tertiary & residential relevant policies in the High-RES

N°	Measures	EU, national and other Legislative, other actors	Implementation in FORECAST and eLOAD
General regulatory measures			
1	Energy Taxation Directive	Directive 2003/96/EC	Fuel tax per fuel type by country affecting the choice of heating systems and building retrofits (e.g. X %)
2	Minimal energy performance standards (MEPS) for further appliances (e.g. further lighting categories, power supply and other ICT devices etc.	Ecodesign Directive	Reduce energy consumption of such devices; further efficiency classes beyond A+++ enter the market (annual decrease rate to be determined)
3	Minimal energy performance standards (MEPS) for fossil heating systems	Ecodesign Directive	Ecodesign Directive
4	Set an administrative framework to check compliance of regulative policies		Increase compliance rate up to 85%; penalties for non-compliance
5	Minimum standards for buildings (EPBD)	Directive on the energy performance of buildings/ nearly zero energy directive	Tightening building envelope requirements: distinction between existing buildings and new buildings; e.g. for new buildings low energy requirements (<=30kWh per m^2/year)
6	Labelling regulation electrical appliances	Energy labelling directive	Increases the preference for energy-efficient appliances (as compared to less EE ones)
7	Labelling regulations for heating systems (including quality assurance particularly heat pumps)	Energy labelling directive	Increases the preference for heat pumps (as compared to fossil systems)
8	Mandatory periodic inspection of heating systems	EC, implementation national	Decrease average life time of heating systems: replacement obligation for heating systems older than 30 years; mandatory energy labelling for new and existing devices older than 20 years in the policy scenario. Exemption for all controllable heating systems (e.g. controllable night storage heaters remain in stock even after threshold year – non-controllable devices will be phased out)
Mainly tertiary sector			
9	Mandatory periodic inspection of main building technology systems such as ventilation, cooling, building automation etc.	EC, implementation national	Decrease average life time of such systems
10	Mandatory “commissioning” of building and building technology systems of new buildings and BT replacement	EC, implementation national	Increase energy-efficiency at these instances by 10 % to 15 %
11	Minimal energy performance standards (MEPS) for medium and large data centres (DC) (first new, than also existing ones)	EC, implementation national	Reducing the PUE indicator, partly re-use of waste energy from DC
General financial support			
12	Provide risk guarantee for large infrastructure investments, e.g. for combined thermal networks	Private sector	Increase the availability/potential for heat pumps and highly efficient cooling systems, increase their efficiency and decrease their costs
13	Create a market for demand side capacity management and DSM (to	EC, implementation national	Activate DSM potentials in eLOAD, depending on prices received from other

	be tapped by so-called aggregators)		REFLEX models
14	National efficiency programs that provide financial incentives (e.g. KfW in Germany)		Decrease investment costs between 10 and 20% (e.g. borehole for heat pumps)
15	National supporting schemes for thermal renovation		Increase financial incentive for thermal renovation leading to an increase of renovation rate (e.g. doubling for residential buildings)
Mainly residential sector			
16	Adjust power market regulation to foster integration of RES and heating systems and own consumption of generation from RES	EC, implementation national	Introduce such systems in the choice set of single and multi-family houses; define share of own generation which is subsidised – subsidy covers RES and network charges – feed-in-tariff provides incentives for own generation

Source: Fraunhofer, TEP

Flexibility mechanisms and learning curve effects

As for industry it is expected that the policy scenario shows a higher need for flexibility than the reference scenario due to the higher share of fluctuating RES. The flexibility potential of the service sector and the households depends mainly on the electricity demand and the demand pattern of each energy service or appliance that may change in the future. Relevant applications of electricity in the context of flexibility and learning curve effects could be:

- Air-Conditioning
- Freezers
- Refrigerators
- Dishwashers
- Dryers
- Washing machines
- Night storage heater
- Electric radiator
- Heat pump
- Sanitary hot water

Experience curves for the most relevant flexibility options will be considered and implemented to estimate the optimal mix.

4.3. TRANSPORT SECTOR

The European Roadmap for moving to a competitive low carbon economy in 2050 has identified a range of emission reduction in the transport sector depending on the rate of technological innovation and different fossil fuel prices until 2050 of about -54 to -67% in 2050 (COM, 2011/0112). These ranges will also be set as target guideline in the High-RES Scenario. Major drivers to a low carbon transport sector will be increased fuel efficiency of conventional drivetrain technologies and improved demand management (e.g. improved public transport, car sharing), but also the diffusion of environmentally friendly vehicles (e.g. electric vehicles). (COM, 2011/0112)

Furthermore, the recent communication from the European Commission on European Strategy for low-emission mobility (COM 2016/501) sets clear and fair guiding principles to shift towards low-carbon economy in transport sector. This document has been taken as reference to set up the policy framework of the High-RES Scenario, making reference to the more ambitious scenarios described in the accompanying document of the EC communication.

The main elements to be considered according to the EC strategy are:

- Increasing the efficiency of the transport system by making the most of digital technologies, smart pricing and further encouraging the shift to lower emission transport modes,
- Speeding up the deployment of low-emission alternative energy for transport, such as advanced biofuels, electricity, hydrogen and renewable synthetic fuels and removing obstacles to the electrification of transport,
- Moving towards zero-emission vehicles, accelerating the transition towards low- and zero-emission vehicles [9] while making further improvements to the internal combustion engine.

The High-RES Policy scenario includes different measures related to these key actions, as reported in the following paragraph. On one hand, a range of measures acting on transport demand and leading to improvements in energy efficiency and transport system efficiency is implemented. These measures are related in particular to road infrastructure pricing (e.g. with the internalisation of external cost), diffusion of Collaborative Intelligent Transport Systems applications, urban policies to promote sustainable mobility and measures promoting efficiency improvements and multimodality. On the other hand, improved fuel efficiency is fostered thanks to application of ambitious vehicle efficiency standards, acting in the low- and zero-emission vehicles area and applied for new cars and vans, but extended also to buses and HDV. Furthermore, a gradual transition towards large-scale penetration of cleaner vehicles (i.e. electric vehicles powered by batteries or fuel cells) is supported by measures focusing on recharging/refuelling infrastructure and advanced research and innovation in electro-mobility. Furthermore, actions focusing on the deployment of low-emission alternative energy for transport are considered.

[9] EU legislation currently refers to low-emission vehicles as vehicles having tailpipe emissions below 50g/km. This would include some plug-in hybrids, full electric cars and fuel cell (i.e. hydrogen-powered) vehicles. The latter two examples also represent zero-emission vehicles.

Policy framework

The following table summarises the policy framework related to the transport sector which are implemented in the High-RES Scenario. In some cases, the measures are the same as in the High-RES Reference Scenario with the assumption that the implementation of the policies is enhanced in order to obtain more consistent impacts in terms of energy saving and emission reduction.

Table 8: Development of transport relevant policies in the High-RES

N°	Action	Measures	Modelling implementation
1	Energy	Energy Taxation	Increased Fuel tax for conventional fuels Reduced fuel tax for electricity, biofuels, hydrogen
2		Fuel Quality	Reduced CO2 emission factor for fuel production
3	Zero-emission vehicles	Electric vehicles penetration	Penetration of EVs in the road vehicle fleet (vehicle cost, learning curves, etc.)
4		Fuel efficiency standard for new cars, vans	Renewal and technology of cars and vans vehicle fleet, reduced fuel consumption factor for cars and vans
5		Fuel efficiency standard for new buses, coaches and HDV	Renewal and technology of vehicle fleet composition for HDV, coaches and buses, reduced HDV, coaches and bus fuel consumption factor at urban level
6	Efficiency of transport system	Road infrastructure charging	Motorway tolls for HDV, LDV, bus and cars Urban road user charging
7		Cooperative Intelligent Transport Systems (C-ITS)	Impacts on road safety, emission factors, fuel consumption factors, speed
8		C-ITS for logistic / Urban freight distribution	Truck load factor
9		Multi-modal transport: regulatory framework for the railway sector	Reduced train passenger and freight time
10	Low-emission energy for transport	Renewable energy	Increased share of biofuels for cars, buses increased share of biofuels for aviation and LDV rail electrification natural gas for maritime, LDV and buses
11		infrastructure for alternative fuels (electricity, natural gas, hydrogen)	**Investments in infrastructure for refuelling system** (electricity, natural gas, hydrogen): impacts on vehicle fleet composition
12	Environment for low-emission mobility	Electricity Market Design proposal to face challenges at distribution level at peak times.	**Changing profile of transport electricity demand during the day**
13		Sharing mobility	Mode split (car sharing, car-pooling)
14		Improving local public transport	Bus passenger cost / time at local level
15		Encouraging active travel (cycling, walking)	Mode split at local level: increased share of slow mode trips
16		CO2 standard for new aircraft	Reduced fuel consumption and emission facto for aviation
17		Energy Efficiency and emissions from shipping	Reduced fuel consumption and emission facto for ships

Source: TRT

Flexibility mechanisms and learning curve effects

Flexibility options within the mobility sectors will mainly occur with the diffusion of mobility services and autonomous driving cars in car sharing fleets. Combined with a higher share of electric cars, fleet operators can shift charging processes during the day taking the passenger transport demand situation into account. Compared to today's charging strategies (mostly at home and in the evening), electric cars can be charged during off-peak hours. An increasing number of cars driven by alternative fuels (e.g. H2 or other alternative liquid fuels) will lead to a higher demand for those fuels and hence can be used by the energy sector to transform off-peak electricity into fuels (power-to-x).

Learning curve effects in the mobility sector will lead to lower production cost of alternative drive technologies of cars, trucks and buses due to higher economies of scale. Hence the purchase prices of these new technologies will decline and the demand will increase. Strong learning effects will therefore accelerate the diffusion of alternative drive technologies within the fleets and lead to higher consumption of electricity or other alternative fuels (e.g. H2).

On global level electric vehicle (EV) deployment targets, cumulative experience in manufacturing EV batteries, economies of scale and cost/price reductions will be relevant. R&D might lead to a higher energy density of EV batteries and impacts on battery pack size per vehicle and average service lifetime (i.e. number of batteries needed over the vehicle lifetime) could play a role as well. Effects on density and battery size would then affect EV purchase price and TCO as well as, among other factors, the speed of EV market uptake.

4.4. POWER SECTOR

The European Roadmap for moving to a competitive low carbon economy in 2050 has identified a nearly full CO_2 reduction goal of -93 to -99% in 2050 in the power sector, which will also be set as target guideline in the High-RES Scenario (COM, 2011/0112). This goal should be reached via a (nearly) complete transformation of the power sector to low-carbon production technologies (e.g. wind and photovoltaic) in 2050. These developments have to be accompanied by substantial grid-investments. (COM, 2011/0112)

Policy framework

Within REFLEX, two models (PowerACE and ELTRAMOD) will be used for analysing the power sector. Both consider the main regulatory framework of the European power sector, for example:

- Emission trading system (ETS) which is regulated by Directive 2003/87/EC among others: Exogenously given prices for CO_2 allowances instead of emission caps determine the power plant dispatch in both models. In this way, repercussions from the ETS on the power sector are considered.
- Internal market in electricity and cross-border exchange which is regulated by Directive 96/92/EC and 2009/72/EC among others: ELTRAMOD considers cross-border trading in EU28 plus Norway and Switzerland concerning their NTC. The focus of PowerACE is internal markets in central Europe. In addition, current frameworks published by entso-e (European Network of Transmission System

Operator for Electricity) are considered in both models. This comprises for example the Ten Year Network Development Plan (TYNDP). New transmission projects, foreseen in the TYNDP, will be implemented in ELTRAMOD.

- Renewable Energy Directive (e.g. 2009/28/EG): In both models, European directives as well as national action plans with regard to renewable energy expansion are considered. European wide or country specific targets will be implemented in the models, to find an adequate technology mix for electricity generation of renewable energy sources. Besides, current activities or results from the SET-Plan will be considered, where appropriate.

Flexibility mechanisms and learning curve effects

It is expected that the share of renewable energy sources (RES) in the electricity system will strongly increase by 2050. As a result, the electricity production becomes more intermittent and flexibility options will be needed. Several technologies exist, e.g. different kind of energy storages, Demand Side Management or transmission. All of them show different technical and economic characteristics. Therefore, a mix of different flexibility options will be needed, to integrate a high share of RES generation. To find the optimal mix, experience curves for the most relevant flexibility options will be considered and implemented in the electricity models PowerACE and ELTRAMOD. In addition, the trade-off between different flexibility options will be investigated.

5. Literature

Bernstein L, Bosch P, Canziani O, Chen Z, Christ R, Davidson O, et al. (2008) Climate change 2007: Synthesis report: An assessment of the intergovernmental panel on climate change. 2008.

Capros P. et al. (2016) EU Reference Scenario 2016, Energy, transport and GHG emissions Trends to 2050. Luxembourg: Publications Office of the European Union. https://ec.europa.eu/energy/en/data-analysis/energy-modelling

COM (2011/0112) COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A Roadmap for moving to a competitive low carbon economy in 2050. COM/2011/0112 final. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0112

COM (2008/2082) COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS - Single European Sky II: towards more sustainable and better performing aviation, {SEC(2008) 2082}

COM (2016/501), COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS- A European Strategy for Low-Emission Mobility {SWD(2016) 244 final}

COMMISSION STAFF WORKING DOCUMENT Accompanying the document COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS - A European Strategy for Low-Emission Mobility {COM(2016) 501 final}

CEU (2008) Council of the European Union. Energy and climate change - Elements of the final compromise. vol. 2008. Brussels: 2008.

Decision 884/2004/EC and expected continuation – 2012 Council agreement on revised TEN-T guidelines Decision 884/2004/EC and expected continuation – 2012 Council agreement on revised TEN-T guidelines

Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products.

Directive 2012/27/EU. 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. OJEU L 315/1 14 Novemb 2012 2012.

Directive 2009/28/EG. Directive 2009/28/EG of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. OJEU L 140/16 5 June 2009 2009.

Directive 2010/31/EU. Directive 2010/31/EU of the European Parliament and of the council of 19 May 2010 on the energy performance of buildings (recast). OJEU L 153/13 18 June 2010 2010.

Directive 2009/28/EG. Directive 2009/28/EG of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. OJEU L 140/16 5 June 2009 2009.

Directive 2010/31/EU. Directive 2010/31/EU of the European Parliament and of the council of 19 May 2010 on the energy performance of buildings (recast). OJEU L 153/13 18 June 2010 2010.

Directive 2009/28/EG. Directive 2009/28/EG of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. OJEU L 140/16 5 June 2009 2009.

Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EECDirective 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles

Directive 2011/76/EU of the European Parliament and of the Council of 27 September 2011 amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures

Directive 2012/34/EU of the European Parliament and of the Council of 21 November 2012 establishing a single European railway area

Directive 2007/58/EC of the European Parliament and of the Council of 23 October 2007 amending Council Directive 91/440/EEC on the development of the Community′s railways and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure

Directive 2012/33/eu of the European Parliament and of the Council of 21 November 2012 amending Council Directive 1999/32/EC as regards the sulphur content of marine fuels

Emission standards for diesel trains (UIC Stage IIIA)

EVI (2016) Global EV Outlook – Beyond one million electric cars. Electric Vehicles Initiative (EVI). OECD/IEA.

ICAO Chapters 3 (emissions)

IMO Energy Efficiency Design Index (EEDI) IMO Resolution MEPC.203(62)

Implementation of MARPOL Convention ANNEX VI 2008 amendments - revised Annex VI

Pachauri RK, Allen MR, Barros V, Broome J, Cramer W, Christ R, et al. (2014) Climate change 2014: synthesis Report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change: IPCC; 2014.

Regulation (EU) No 333/2014 of the European Parliament and of the Council of 11 March 2014 amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO 2 emissions from new passenger cars

Regulation (EU) No 253/2014 of the European Parliament and of the Council of 26 February 2014 amending Regulation (EU) No 510/2011 to define the modalities for reaching the 2020 target to reduce CO 2 emissions from new light commercial vehicles Text with EEA relevance

Regulation (EU) 2009/28/EG. Richtline 2009/28/EG vom 23. April 2009 des Europäischen Parlaments und des Rates zur Förderung der Nutzung von Energie aus erneuerbaren Quellen und zur Änderung und anschließenden Aufhebung der Richtlinien 2001/77/EG und 2003/30/EG. AblEU Nr L 140/16 v 562009 2009.

UNEP (2002) Global Environmental Outlook 3. London2002.

UNEP (2007) Global Environmental Outlook. GEO 4. Environment for development. Nairobi, Kenya: United Nations Environment Programme; 2007.

UNEP (2012) GEO5 - Global Environmental Outlook 5. Environment for the future we want. United Nations Environment Programme; 2012.

van Vuuren DP, Kok MTJ, Girod B, Lucas PL, de Vries B. (2012) Scenarios in Global Environmental Assessments: Key characteristics and lessons for future use. Global Environ Chang. 2012;22:884-95.

Watson RT, Albritton DL. (2001) Climate change 2001: Synthesis report: Third assessment report of the Intergovernmental Panel on Climate Change: Cambridge University Press; 2001.