Constructive Design and Building Construction

Master Thesis – Susanne Eiselt

Renovations of European Building Stocks towards the “Fit for 55” Climate Package

I. Zielsetzung und Motivation

“Buildings are the single largest energy consumer in Europe, using 40% of our energy, and creating 36% of our greenhouse gas emissions. That is because most buildings in the EU are not energy efficient and are still mostly powered by fossil fuels. We need to do something about this urgently, as over 85% of today's buildings will still be standing in 2050, when Europe must be climate neutral.”

Kadri Simson, EU Commissioner for Energy

In light of these figures, decarbonization requires renovation of the existing building stock. Nevertheless, the annual weighted energetic refurbishment rate remains persistently low at around 1%. Given the increased focus on building vulnerabilities due to the COVID-19 pandemic and to implement the Green Deal, the EU Commission launched the Renovation Wave for Europe in 2020 with the aim of doubling the annual renovation rate and reducing carbon emissions over the entire life cycle of a building. However, as previous measures are insufficient to achieve the climate targets and to adjust the related specific European legislation, the so-called “Fit for 55” package of proposed measures was announced in 2021.

II. “Fit for 55” Climate Package

Objective of the set of proposals is to reduce Green House Gas (GHG) emissions by 55% by 2030 compared to 1990 levels. In total, it comprises 13 directives and amendments concerning climate, energy and transport-related regulations. Concerning building stock emissions, the key measures are contained in the following:

1. Energy Performance of Buildings Directive (EPBD)
   Reclassification of energy efficiency classes, obligatory renovations and renovation passports, emission-free new buildings, energy certificates, e-mobility charging stations and national renovation plans.

2. Energy Efficiency Directive (EED)
   Renovation of public buildings, reduced energy use in the public sector and energy performance contracts (EPC’s).

3. Emission Trading System (ETS)
   European emissions trading scheme for the buildings and road transport sectors (EU-ETS 2), Social Climate Fund and Innovation Fund.

4. Renewable Energy Directive (RED II)
   Energy Mix, renewable energy sources, heating and cooling and district heating.

III. Building Stock Characteristics I

The Buildings Performance Institute Europe estimates that in the EU27, plus Switzerland and Norway, 25 billion m² of floor space exists, which is roughly equivalent to the land area of Belgium with 30,528 km². Overall, the building stock is characterized by enormous heterogeneity, as result of cultural diversity and historical development. This is reflected in a range of building characteristics, from typologies and construction techniques to energy intensities, as illustrated in Figures 1 to 7.

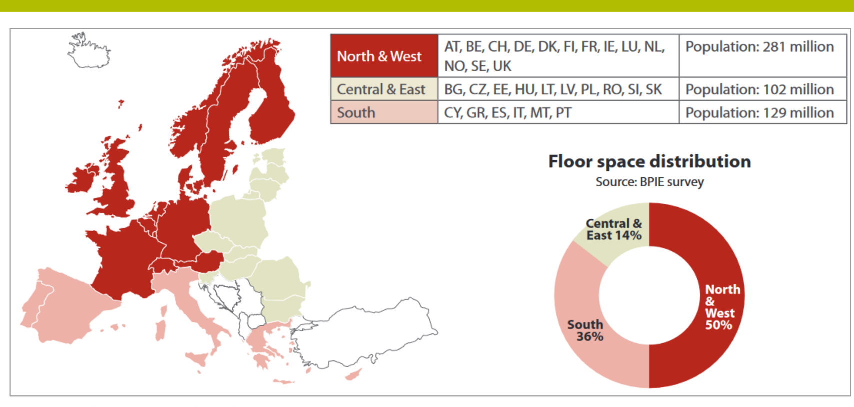

Fig. 1: Floor space distribution across European regions
Source: Economidou 2011, p. 8

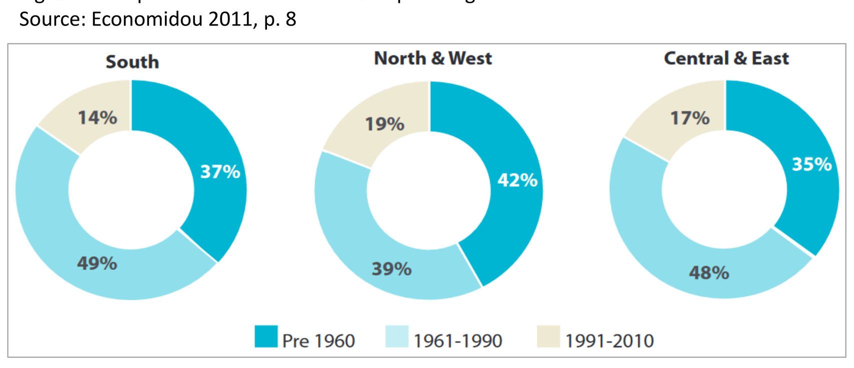

Fig. 2: Age categorization of housing stock in Europe according to region
Source: Economidou 2011, p. 9

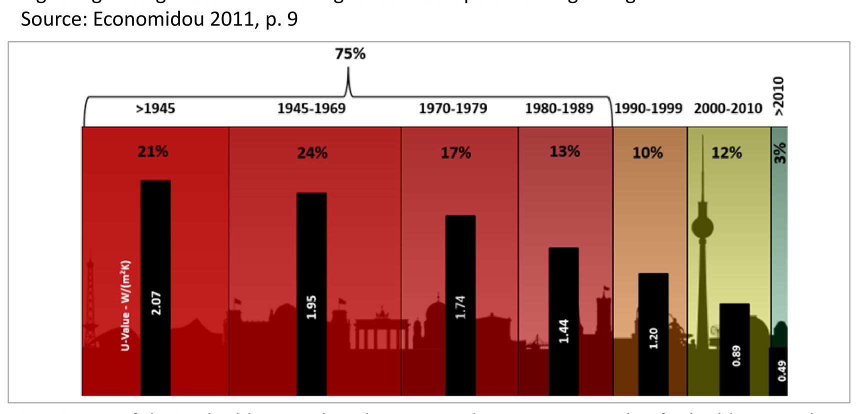

Fig. 3: Age of the EU building stock and corresponding average U-value for building envelops
Source: d'Angiolella 2017, p. 2

III. Building Stock Characteristics II

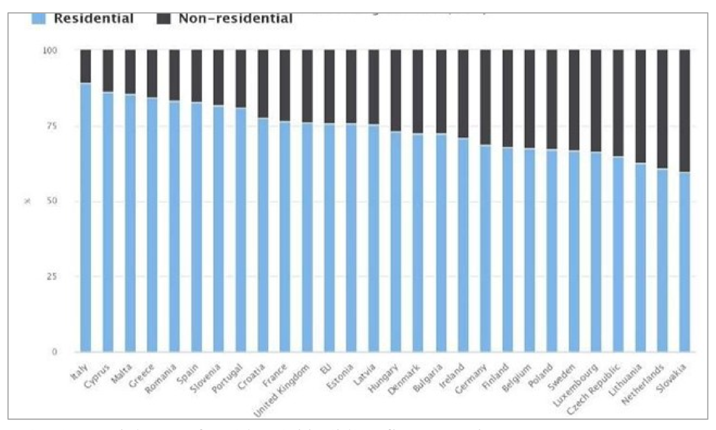

Fig. 4: Breakdown of residential building floor area by country
Source: EU 2021

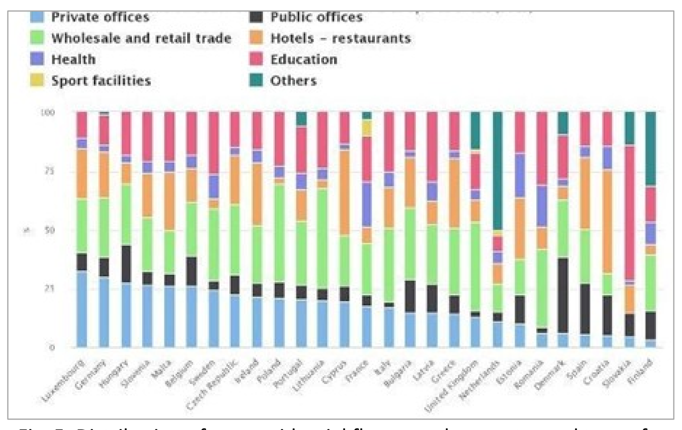
Fig. 5: Distribution of non-residential floor area by country and type of use
Source: Bertelsen and Mathiesen 2020, p. 10

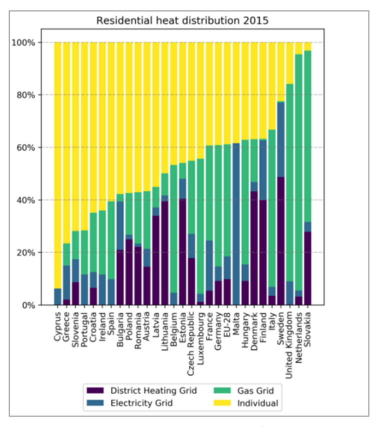
Fig. 6: Share of residential heat consumption from individual heating or delivered via district heat networks, gas grids or electricity grids per member state
Source: EU 2021

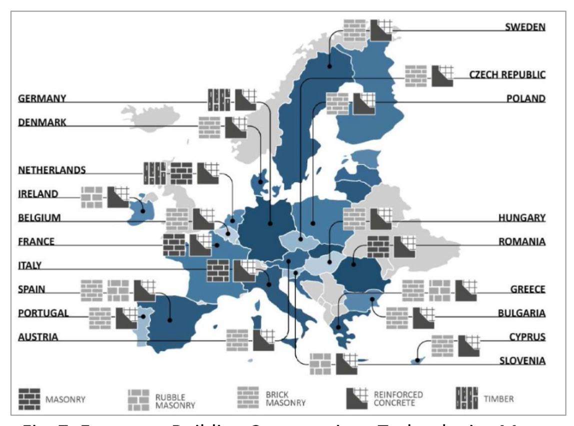
Fig. 7: European Building Constructions Technologies Map
Source: Landolfo 2020, p. 14

IV. Emission Characteristics

Worldwide, 39% of GHG emissions originate from the building sector, according to the United Nations. 11% of emissions are attributable to embodied emissions (phase A1-A5 in Figure 14), 28% to operational emissions.

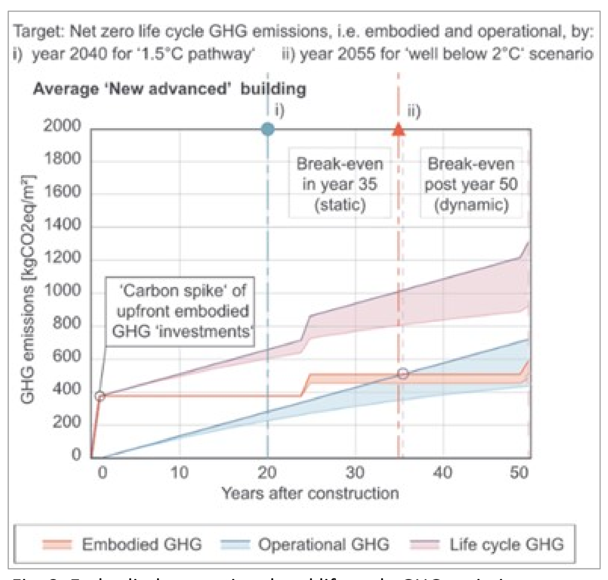

Fig. 8: Embodied, operational and life cycle GHG emissions over a paradigmatic building's life cycle
Source: Röck 2020, p. 9

1. Embodied emissions
On average, eastern European countries exhibit the greatest amount of GHG emissions per m², followed by western Europe, while in northern Europe, embodied carbon values are significantly lower (half of the average per m² emissions of eastern Europe).

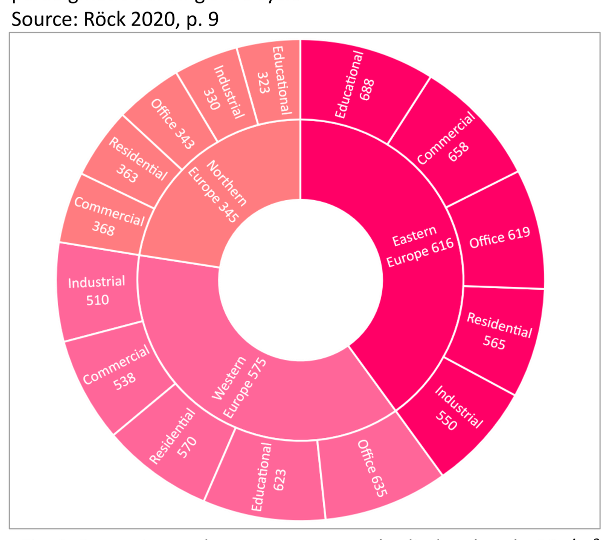
Fig. 9: Per region and sector average embodied carbon $kgCO_2/m^2$
Source: Aspen 2021, p. 12-13, own representation

2. Operational emissions
Gas is the primarily used fuel type in households (approx. 913.000 GWh in 2020) 32%, followed by electricity (25%), renewables (20%), petroleum products (12%), derivated heat (8%) and solid fuels (3%). The total of emissions equals roughly 964.1Mt CO_2 equivalent.

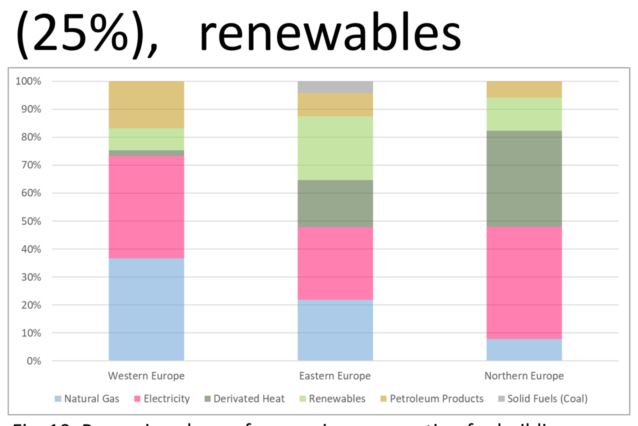
Fig. 10: Per region share of energy in consumption for buildings
Source: EU 2021, own representation

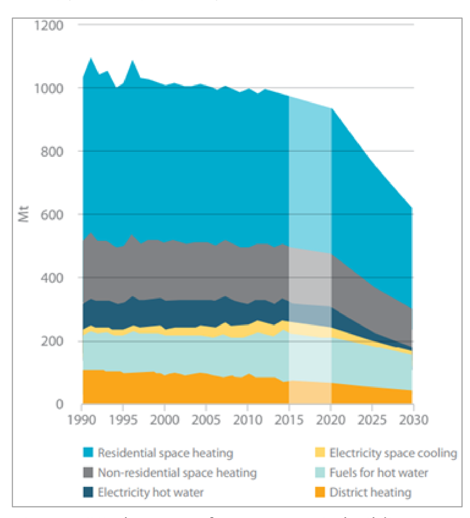
Fig. 11: CO_2 by type of energy use in buildings
Source: Roscini 2020, p. 9

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V. Scenario Analysis

To predict possible development trajectories of the GHG emissions of the building stock until the year 2030 in light of the measures of the Fit for 55 climate package, scenario analysis is chosen as method. The adjacent figure depicts how possible futures are systematically approached are are systematically approached.

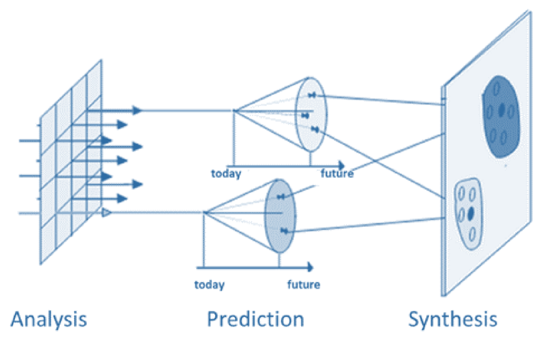

Fig. 12: Scenario analysis phases
Source: Gassmann and Kobe 2006, p. 19, own translation and adaption

V.I. Key impact factors

Key factors expected to influence the future development of building stock related CO_2 emissions are identified in two main categories: regulatory level factors (targets, indicators and obligations of the EU administrative bodies in the context of the Fit for 55 package), as well as environmental factors, referred to as external level (not directly influenced through building-specific regulations.

Fig. 13: Key impact factors
Source: own representation

V.II. Weighting of impact factors

At the building level, life cycle stages correspondding to the classification of the European Norm 15978 [Sustainability of construction works] are applied. Subsequently, an evaluation of the influence of the respective factors is performed. Results indicate: the operational section is influenced the most by factors of the exogenous level, while resource availability, supply chains, obligatory renovations and renovations of public buildings exert the highest influence.

EXOGENE LEVEL		Factor	Product Stage (A1 Raw Materials, A2 Transport, A3 Manufacturing)	Assembly Stage (A4 Transport, A5 Assembly)	Use Stage B1–B5 (Use, Maintenance, Repair, Replacement, Refurbishment)	Use Stage B6 Operational Energy Use (Appliances, Cooking, Lighting, Cooling, Space Heating) / B7 Operational (Domestic Hot Water, Water)	End of Life Stage (C1 Deconstruction Demolition, C2 Transport, C3 Waste processing, C4 Disposal)	Beyond System (D1 Reuse, D2 Recovery, D3 Recycling)	Active Sum
Regulatory Level [influencable steering factors - Fit for 55]	EPBD	Obligatory renovations	1	0	2	2	2	1	8
	EPBD	Net-Zero new buildings	1	1	0	2	0	1	5
	EPBD	National Building Renovation Strategies	1	1	2	2	1	0	7
	EED	Renovation of public buildings	1	1	2	2	1	1	8
	EED	Reduced Energy Use Public Sector	0	0	2	2	0	0	4
	EED	Energy Performance Contracts (EPCs)	1	1	2	2	1	0	7
	ETS	Emission Trading	0	0	1	2	0	1	4
	ETS	Social Climate Fund	1	1	2	1	0	0	5
	RED	Energy Mix	1	1	1	2	0	0	5
	RED	Renewable Energy Sources	0	0	1	2	0	0	3
	RED	Heating and Cooling	0	0	2	2	0	0	4
	RED	District Heating	0	0	0	2	0	0	2
External Level [non influencable environmental factors]		Resource availability	2	2	2	1	1	2	10
		Supply Chains	2	2	2	0	2	2	10
		Sources of primary energy	1	1	1	2	0	0	5
		Climate (HDD/CDD)	1	0	1	2	0	0	4
		Amount / kind of household appliances	0	0	0	2	2	0	4
		User behaviour (consumption)	0	0	0	2	0	0	2
		Floor space required per capita	2	1	0	2	0	1	6
		Investments	2	2	1	1	1	1	8
		R&D progress (e.g. insulation)	0	0	2	1	2	1	6
		Inflation	2	2	2	2	0	1	9
Passive Sum			19	16	28	38	13	12	

Evaluation: How strongly does each influencing factor of the exogene level influence each area of the building level?

The influence is expressed via the following scoring system:
0 = No influence
1 = Weak or indirect influence
2 = Strong influence

Passive Sum: how significantly is an area influenced?
Active Sum: how significantly does one area influence other areas?

Fig. 14: Evaluation of the impact factors according to the matrix method
Source: own representation

V.III. Descriptor analysis

EXOGENE LEVEL – Regulatory Level [influencable steering factors - Fit for 55]

	EPBD: Obligatory renovations	EPBD: Net-Zero new buildings	EPBD: National Building Renovation Strategies	EED: Renovation of public buildings	EED: Reduced Energy Use Public Sector	EED: Energy Performance Contracts (EPCs)
Description	Residential buildings have to achieve at least energy efficiency class F by 2030, non-residential buildings by 2027 (hence in each country 15% of the building stock is subject to renovation)	All newly erected public buildings must be constructed as Net-Zero-Energy buildings by 2027	Roadmaps for fossil fuel free heating and cooling by 2040, therefore in this study 50% reduction by 2030 is assumed	Renovation of 3% of the total floor area of public buildings annually is achieved	A reduced energy consumption in the public sector by 1.7% per year is targeted	Energy Performance Contracts (EPCs) to refurbish large non-residential buildings
Positive	15% of wort performing buildings reach efficiency class A	low embodied energy of construction materials	-50% fossil fules for heating and cooling overall	3% renovation of public buildings annually [x10=30%]	-1,7% energy use in the public sector annualy [x10=-17%]	refurbishments
Stable	15% of wort performing buildings reach efficiency class D	high/medium embodied energy of construction materials	-20% fossil fuels for heating and cooling overall	1% renovation of public buildings annualy	-0,55% energy use in the public sector annualy	view refurbishments
Negative	15% of wort performing buildings reach efficiency class F	high embodied energy of construction materials	-5% fossil fuels for heating and cooling overall	no/less than 1% refurbishments	no change	no/very view refurbishments

	ETS: Emission Trading	ETS: Social Climate Fund	RED: Energy Mix	RED: Renewable Energy Sources	RED: Heating and Cooling	RED: District Heating
Description	43% reduction in emissions by 2030 compared to 2005- Certificates issued for fossil fuels such as heating oil (combustion-related) - 15% annually viewer certificates	Aids vulnerable households (in energy poverty) in renovating, refurbishing, or investing in the heating systems	By 2030, the share of renewable energy in the energy mix shall reach 40%. Starting from approximately 20% in 2019 / 2020, this corresponds to an annual plus of 2%.	Buildings shall obtain 49% of their energy from renewable sources in 2030	In the heating and cooling sector, the share of renewable energies shall increase by 1.1% per year.	Renewable energy share of district heating shall increase by 2.1% annualy
Positive	-43% fossil fuel use in buildings	investments in residential dwellings: 1% deep energetic renovations annually	50% renewable energies in energy mix	49% renewable energy sources overall	+2,2% renewables in heating and cooling annually [x10=+22%]	+2,1% renewables in district heating annually [x10=+21%]
Stable	-20% fossil fuel use in buildings	investments in residential dwellings: 0,5% deep energetic renovations annually	40% renewable energies in energy mix	32% renewable energy sources overall	+1,1% renewables in heating and cooling annually	+1% renewables in district heating annually
Negative	no reduction of fossil fuel use in buildings	investments in residential dwellings: 0,2% deep energetic renovations annually (status quo: 0,12%)	25% renewable energies in energy mix	25% renewable energy sources overall	+0,5% renewables in heating and cooling annually	no change

EXOGENE LEVEL – External Level [non influencable environmental factors]

	Resource availability	Supply Chains	Sources of primary energy	Climate (HDD/CDD)	Amount / kind of household appliances
Description	Availability (kind) of goods	Availability (speed) of goods	Composition of energy mix	Amount of HDD and CDD over the course of one year	Energy demand of appliances in buildings
Positive	Güter sind in der Menge Verfügbar, in der sie benötigt werden	Güter werden in der Geschwindigkeit geliefert, in der sie benötigt werden	55% renewables	wenige Extremwetterereignisse	reduced consumption
Stable	Etwas schwieriger Ressourcenverfügbarkeit	Etwas verlängerte Lieferzeiten	45% renewables	leicht veränderte Anzahl an HDDs und CDDs	no change
Negative	Hemmung: Ressourcenknappheit führt dazu, dass energetische Sanierungsrate verringert wird	Hemmung: Verlängerte Lieferzeiten führen dazu, dass energetische Sanierungsrate verringert wird	35% renewables	viele Extremwetterereignisse - mehr kältere und mehr heißere Tage	increased consumption

	User behaviour (consumption)	Floor space required per capita	Investments	R&D progress (e.g. insulation)	Inflation
Description	Energy demand of occupants	Development of per capita available and demanded floor space	Amount of money spent on deep energetic refurbishments	Availability of insulation materials (with low embodied energy), which reduce (operational) energy demand	Amount of money spent on renewable energy supply or deep energetic refurbishments
Positive	reduced consumption	decreasing floor space	increased spending on deep energetic refurbishments	utilization of new, more efficient materials	increased spending on renewable energy supply and deep energetic refurbishments
Stable	no change	stagnant development	same spending on deep energetic refurbishments	utilization of existing, more efficient materials	same spending on renewable energy supply and deep energetic refurbishments
Negative	increased consumption	growing per capita floor space	decreased spending on deep energetic refurbishments	utilization of the same materials as today	decreased spending on renewable energy supply and deep energetic refurbishments

Fig. 15: Possible trajectories (ranges of the developments) of the key factors
Source: own representation

V.IV. Scenario generation

In the descriptor analysis, three possible development trajectories until the year 2030 were generated, whereof future images emerge: a clearly positive one, a clearly negative one as well as an ambivalent one, neither extremely positive, nor extremely negative.

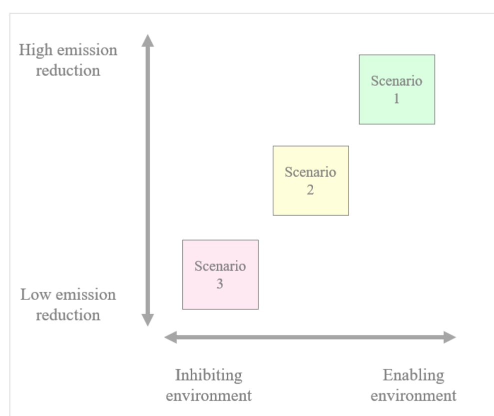

Fig. 16: Future projections
Source: own representation

Scenario 1, the best case, is the most effective in terms of achieving the objectives: high regulatory effectiveness and an enabling environment ensure a high level of emission reduction. Under the circumstances of moderate regulatory effectiveness and an unaltered environment, scenario 2 is moderately efficient towards climate neutrality. In the worst case, scenario 3, effectiveness and efficiency of the measures of the Fit for 55 package are very limited. In conjunction with an inhibiting environment, emission reduction levels are low.

VI. Multicriteria Assessment

To evaluate the efficiency of the scenarios towards climate neutrality (by GHG emissions, social impacts, cost estimation), methodology of multicriteria assessment is chosen. It enables structuring of a decision-making process many alternatives with different consequences are available.

Topic	Weight	Objective	Relative weight	Criteria	Relative weight	Measure	Relative weight	Mark	SCENARIO 1 Score	SCENARIO 2 Score	SCENARIO 3 Score
CO2 [GHG protocol criteria/scopes adapted]	75%	Stationary Energy	60%	Emissions from fossil fuel combustion and fugitive emissions	33%	residential	37,50%	0,1	3	2	1
						non-residential	12,50%	0,03	4	2	1
						energy production/generation	50%	0,13	3	2	1
				Emissions from consumption of grid-supplied energy	33%	residential	37,50%	0,1	4	3	2
						non-residential	12,50%	0,03	4	3	2
						energy production/generation	50%	0,13	3	2	1
				Transmission and distribution losses - building energy class-insulation	33%	residential energy efficiency class/building standard	75%	0,2	4	3	2
						non-residential energy efficiency class	25%	0,07	3	3	2
		Waste	10%	Emissions generated from waste generated in the demolition industry but treated out-boundary	100%	landfill	60%	0,08	1	1	1
						treated	20%	0,03	1	1	1
		Industrial Processes	30%	Emissions from industrial processes - construction industry	100%	processes	50%	0,05	3	2	2
						use	50%	0,05	3	2	1
Weighted Sum									2,88	2,08	1,24
Social impacts [Social Sustainability Barometer of the Energy Transition adapted]	15%	Indirect impacts	20%	Energy consumption (residential)	50%			0,01	4	3	1
				Domestic production (decentralized, PV-roofs)	50%			0,01	2	1	1
		Direct impacts	80%	Cost of energy as a proportion of total cost of living (affordability)	40%			0,056	3	2	1
				Civic participation	15%			0,012	2	2	2
				Received renovation grants	25%			0,02	3	1	1
				Fuel poverty / no access	15%			0,013	2	1	1
Weighted Sum									0,276	0,168	0,112
Cost estimation [Agora Energiewende adapted]	10%	Concerning construction sector	60%	Costs in the building sector	100%	Costs in the building sector	100%	0,1	4	3	1
		Concerning fuels	40%	Electricity	50%	Costs of providing electricity, process heat and network feed-in	50%	0,015	3	3	2
						Electricity grid expansion costs	50%	0,015	3	2	1
				Other fuels	50%	Heat network costs	50%	0,015	2	2	1
						Gas network costs	50%	0,015	3	1	1
Weighted Sum									0,535	0,42	0,22
Total Weighted Sum									3,691	2,668	1,572

Note:
very high impact = 4
high impact = 3
medium impact = 2
low impact = 1

Fig. 17: Multicriteria assessment of scenarios
Source: own representation

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