Strategies to overcome the dilemma in renovating and integrating HPs and RE into the building stock

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Abstract

Considering the overall limited availability of renewable electricity and (district) heat together with the competing demand by industry and transport, deep thermal renovation (TR) of buildings and a rapid phase out of fossil-based heating systems is crucial to achieve the overall climate targets. Independent of the actual choice of the path to the required phase-out of fossils, it will lead to significantly increasing shares of renewables (RE) in the electricity system. This increasing share of RE will lead to a significant reduction of the CO_2 conversion factor for electricity. This will also relevantly influence the CO_2 conversion factor of DH, when, as anticipated to a large extent central large-scale HPs are involved. The dilemma is that in such a scenario, with proceeding time, the deep TR of buildings and the further integration of onsite PV (coupled to HPs) will not any more influence the CO_2 emissions of the building in a relevant way. This would lead to a decreasing motivation to implement high ambition targets on building level. However, high ambition levels will be required to reach the overall goal of the phase-out of fossil energy. This requires an energy policy approach instead of market incentives, i.e. CO_2 tax will not sufficiently trigger the required transition process but instead CO_2 budgets have to be defined.

Keywords: Heat Pumps; Renewables;Thermal Renovation; Phase-out; Energy Scenario; Building Stock; Transition; CO_2; Dilemma

1. Introduction

1.1. Buildings and Energy Transition

On European level (EPBD), ambitious goals have been set implementing nearly zero energy buildings (nZEB) and the target to integrate onsite (or nearby) renewables [1]. Massive integration of renewables (RE) shall lead to Net Zero Energy Buildings (NZEB) or even Positive Energy Buildings (PEB). Extending the system boundary to blocks and districts allows to unlock efficiency potentials of the electric and thermal energy of neighborhoods leading to the goal of Positive Energy Districts (PED) (IEA EBC Annex 83, IEA HPT Annex 61), see e.g. [2].

Contrariwise, with the recently growing need to rapidly phase-out fossil energy-based heating systems, a trend can be seen that HPs and direct electric (DE) heating are implemented in existing buildings (i.e. without thermal renovation) as an apparently cheaper and faster solution (IEA HPT Annex 50).

However, due to the overall limited availability of renewable electricity and (district) heat together with the competing demand by industry and transport, deep thermal renovation (TR) of buildings and a rapid phase out of fossil-based heating systems is crucial to achieve the overall climate targets. The change from gas- or oil-based heating systems to heat pumps (HP) is (often) only technically feasible in combination with deep TR and generally only recommended in combination with it. However, there are both technical and non-technical barriers and challenges [3].

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A rapid phase out of fossil-based heating systems requires a significant boost in the exchange rates. The heat demand of buildings will increasingly be covered by HPs and district heating (DH) and in a minor part by DE systems. Biomass, partly in combination with solar thermal can only be applied up to its limited availability and taking into account the need of biomass in the industry and traffic sector [4]. A decarbonized DH system will consist of biomass CHP, heating plants, large-scale HPs and to some extent geothermal and solar thermal. Therefore, a significant increase of DH's extents and a massive increase of HPs should be taken into consideration [5].

Constraints are next to the limit of available biomass for the building sector (with the competition of other energy consuming sectors and growing food), the limit of economically expanding DH networks and the large-scale production and installation of HP and RE. In addition, a number of barriers/gaps have to be addressed in such a transition process, which are acc. to [3]

- Technical gap: Replacing (decentralized) oil, gas and E-boilers in multi-apartment buildings requires solutions for which currently dedicated HP (system) solutions are not available on the market.
- Owner-user gap: The building owner is often not the beneficiary of the investment, but the tenant is.
- Social gap: Mixed housing (tenant, owner structure) might be an unbreachable obstacle, if e.g. some parties did replace gas boilers recently, while others alternatively replaced windows.
- Financial gap: Renovation might be economically feasible considering life-cycle costs, but high investments are required immediately, which may surpass liquidity constraints.

Without energy efficiency measures in buildings, the electric energy demand increases when switching from fossil energies to HP-based heating systems. This would lead to an increase of the so-called winter gap [6] in a future energy system based on volatile renewable resources (wind, PV).

In the perspective of the energy transition the infrastructural and technological lock-in in the building sector is a limiting aspect considering the long lifetime of buildings and building components [7]. Since building components have a typical lifetime of several decades, insufficient measures taken now will have a long-term effect [8]. This so-called 'carbon lock-in' highlights the need of rather deep TR measures than fast incomplete measures. As an example, a newly installed gas boiler with a lifetime of 20 years becomes a 'stranded asset' and will prevent phase-out of gas but replacing it before end of life is critical in terms of economic considerations. In this perspective, the role of buildings with the possibility of deep TR and switching from fossil-based to HP-based heating systems is of primary importance in achieving the goals of the energy transition and has to be seen as one of the important columns of the energy policy strategy.

1.2. Aim of and structure of this work

In such a scenario of the energy transition, with proceeding time, the deep TR of buildings and the further integration of onsite PV (coupled to a HP) will not significantly influence the CO_2 emissions of the building, which would lead to a decreasing motivation to reach high ambition goals on building level. However, high ambition levels will be required to reach the overall goal of the phase-out of fossil energy in the electricity system and in district heating networks.

Using a simple building stock model, different scenarios of deep TR and integrating HPs and RE will be discussed in terms of environmental impact (i.e. CO_2 emissions) highlighting possible strategies to overcome this energy transition dilemma.

In section 2, Methods, the model and the assumptions are described and different scenarios are developed. In section 3, Results, the scenario results are shown in terms of secondary energy and CO_2 emissions and are discussed from the perspective of the building stock and from the perspective of an individual building. From the results strategies are developed and summarized and concluded in section 4.

2. Method

2.1. Building Stock and Energy System Model

The model represents a generic district and analyses the primary energy demand (P-E) and CO_2 emissions considering transport and conversion for a given useful energy demand (U-E) and consists of (from right to left in the Sankey in Fig. 1):

- the demand, i.e. the useful energy (UE): space heating (SH), domestic hot water (DHW) as well as appliances and auxiliaries,

- the heating systems: fuels (oil, gas, biomass), direct electric (DE) heating, heat pump (HP) and district heating (DH) and
- the energy system consisting of combined heat and power (CHP) and district heating plants (DHP).

The supply side (left), the required secondary energy (S-E), is provided by fossil energy sources (oil, gas), biomass (bio) and to some extent renewable electricity (RE E: hydro, wind, PV) and renewable and waste heat (RE H: industrial waste heat, waste incineration, geothermal, solar thermal).

Using conversion factors (see section below), from the S-E the primary energy (P-E) and CO_2 emissions are calculated.

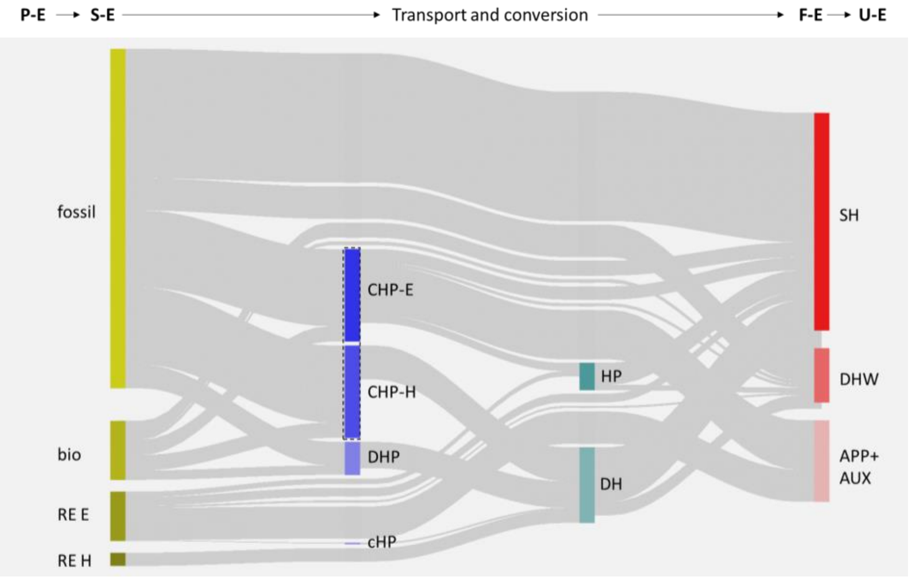


Fig. 1. Sankey Diagram[1] of the Baseline system with high share of fossil (oil, gas) for direct use in buildings (boiler) and for combined heat and power plants (CHP) as well as district heating plants (DHP) and existing (inefficient) building stock with high space heating demand (SH), central heat pumps (cHP) in district heating (DH) play a minor role as do decentral heat pumps (HP) in buildings for space heating (SH) and domestic hot water (DHW).

2.2. Decarbonization Scenarios

The year 2025 is considered as baseline (see section below for details) and the scenario is developed until 2050. For the Building Stock (BS) and for the Energy System (Electricity E and District Heating DH) each three ambition levels (AL) are considered.

- Const (= BAU)
- IMPROVE
- AMBITION

For the Building Stock, BAU means no (relevant) reduction of the HD, IMPROVE means a reduction from 80 kWh/(m² a) to 55 kWh/(m² a) and AMBITION means a reduction to 30 kWh/(m² a) until 2050.

For the Energy System, BAU means slow phase-out of fossil fuels (oil, gas) and no relevant increase of RE in the electricity system and district heating systems, IMPROVE means a relevant reduction of fossil energies and AMBITION a high ambition level, thus that fossils are reduced (directly switching from fuels to electricity (E) and district heating (DH) and indirectly in E and DH) to a remaining very low share. This leads to a massive extension of RE (Biomass CHP as well as wind and PV) in the electricity mix and involves Biomass CHP and HPs in DH.

Furthermore, two different paths are defined, one with focus on individual (i.e. building-wise) HPs and one which is DH dominated and thus includes a higher share of central HPs. This leads to 18 variants in total as shown in Fig. 2.

[1] Ranran Wang (2022). Sankey Diagram (https://www.mathworks.com/matlabcentral/fileexchange/75813-sankey-diagram), MATLAB Central File Exchange. Retrieved November 2022; modified

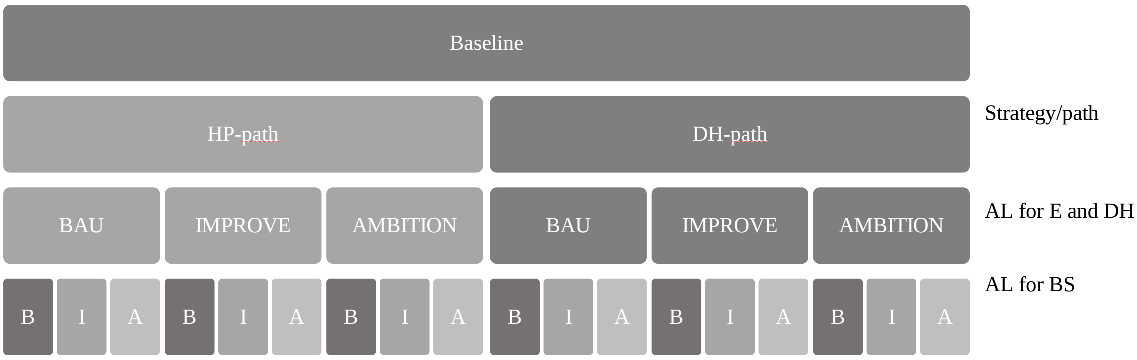


Fig. 2. Overview of Scenarios (transition paths) starting from the baseline with two different paths (individual HP or DH) and with different Ambition Levels (AL) for Electricity (E) and District Heating (DH) as well as for the Building Stock; B: BAU, I: IMPROVE, A: AMBITION

2.3. Building Stock Model - Baseline

The simple building stock (BS) model consists of 100 buildings (i.e. 100 %) with an average treated area of A_T = 150 m². The BS with constant number of buildings with the following properties (Table 1) is heated with a mix of fuel, direct electric heating (DE), decentral heat pumps (HP) and district heating (DH) as in Table 2. In all scenarios fuels for heating are reduced to minor shares of 2.5 % in terms of energy demand. Direct electric heating (DE) is assumed to increase from 10 % in 2025 linearly to 15 % in 2050. In all scenarios a switch from fossil fuels to biomass is assumed but considering that the absolute amount of biomass is limited for the building sector. Gas boiler (condensing) are assumed to have an overall thermal efficiency of 85 %, while oil and biomass boilers are calculated with 80 % efficiency. The share of DH increases in the DH-path from 25 % to 60 % and in the HP-path to 35 %.

Table 1. Building stock characteristics.

	BAU	IMPROVE	AMBITION
Space Heating Demand SH / kWh/(m² a)	80	55	30
Domestic Hot Water Demand DHW / kWh/(m² a)		15 + 5	
Appliances and auxiliaries / kWh_{el}/(m² a)		20 + 5	

Table 2. Baseline building stock (BS) heating system, share in %.

	Baseline	Remark
Fuel (building/flat-wise boiler)	55	Phase-out
- oil	30	Fast phase-out
- gas	60	
- bio	10	Limited absolute amount
DE	10	Limited to slight increase
HP (decentral, i.e. building/flat wise)	10	Strong increase
DH	25	Strong increase in DH-path

2.4. Energy System - Baseline

For sake of simplicity the energy system is modelled by means of annual balancing starting from the baseline until 2050 in steps of 5 years and consists of fuels (oil, gas and biomass), an electric grid and DH. Both systems, electricity and DH are coupled on several levels: directly via CHP, and indirectly via central HPs in the DH system and decentral HPs in buildings and are influenced by the choice of the ambition level in the building stock (BS) through the reduction of SH demand in the DH and via DE and HP in the electricity demand, see also Fig. 1 (above).

Depending on the choice of the ambition level in the BS and the path (DH or HP) the energy demand in the DH can either decrease or increase. The electricity demand can either remain constant (in the DH path and in case of high ambition level), or in all other cases will increase.

The overall goal is to compare different paths for the phase-out of fossils. As shown in Fig. 1 (above) this can be achieved on building level by different combinations of (deep) TR, switching from fossil-based heating to biomass-based heating, DH or HP and by decarbonizing the electricity and DH. Both in the electricity mix and the DH system biomass is present. Due to the limited potential of biomass for energetic use, biomass is limited as direct fuel or as fuel in CHP or District Heating Plants (DHP) in all scenarios to a maximum increase of 100 % with respect to the baseline.

2.4.1. Electricity

The electricity system consists of fossil (gas) and biomass CHP, Hydro (with a constant absolute contribution), Wind and PV. Coal and nuclear energy are excluded in this scenario (baseline 2025).

In a scenario with increasing electricity, to some extend biomass CHP can be increased, the rest hast to be covered by extending wind and PV. On-shore and off-shore wind are not distinguished. Furthermore, onsite (building integrated) and ground-mounted PV are not distinguished. Imports and exports of electricity are disregarded (i.e. either not existing or balanced). The absolute contribution of hydro is assumed to be constant (limited extension potential).

Table 3. Electricity mix of baseline, share in %.

	share	Remark/Constraint
Fossil CHP	50	phase-out
Biomass CHP	10	absolute limit
Hydro	25	absolute limit
Wind	5	
PV	10	

2.4.2. District Heating

District heating (DH) refers to (sufficiently) large DH systems with CHP (block heating is accounted to single building heating systems, here). The contribution to DH of the baseline is summarized in Table 4. DHP are assumed to have an efficiency of 80 %. The thermal efficiency of CHP plants is 40 % and the thermal energy is limited by the electric output (electricity-driven CHP). DH losses are assumed to be 10 % with respect to the useful energy. Waste heat, geothermal and solar thermal absolute contribution is assumed to be constant.

Table 4. District heating (DH) system of baseline, share in %.

	share	Remark/Constraint
Waste Heat and waste incineration	15	absolute limit
Geothermal and solar thermal	2.5	constant absolute contribution
central Heat Pump (Heat)	2.5	
Bio CHP	10	limited by electricity generation, absolute limit
Bio DHP	10	absolute limit
Fossil CHP	35	limited by electricity generation,
Fossil DHP	25	Phase-out (in IMPROVE and AMBITION)

2.4.3. Heat Pumps

Heat pumps play the predominant role in both paths (HP and DH). The central and decentral HPs are modelled with a simple Carnot based approach with a Carnot performance factor η_c:

$$COP_{HP} = \eta_c \cdot COP_c \quad (1)$$

$$COP_c = \frac{T_{max}}{T_{max} - T_{min}} \quad (2)$$

$$COP_{Sys} = (1 - \mathrm{a}) \cdot COP_{HP} + a \cdot COP_{DE} \quad (3)$$

For the decentral (building- or flat-wise) HPs, the following assumptions were made: a Carnot performance factor of 0.36, a flow temperature of 65 °C at an average ambient temperature of 10 °C and share a of direct electric (DE) heating of 15 % with COP_{DE}= 1 (bivalent system) the system COP = 2.

For the central HPs (DH level), the flow temperature is assumed to be 95 °C, the average source temperature is 15 °C and the Carnot performance factor is $\eta_c = 0.44$. This results in an average HP and system COP of 2.

It is noteworthy that a COP of 2 is relatively low with respect to other studies. However, if a fast and broad implementation of HPs in the building stock is assumed, a high-quality low-temperature heating system cannot be hypothesized. Hence, the assumption of higher COP would be very optimistic. In case of the scenario with high ambition level in the BS, a lower heating load and a lower required flow temperature could be expected, which would lead to a slightly better COP. The influence on the resulting electricity demand would be still relatively low as also the demand is anyway significantly lower. As an example, with a COP of 2.5 instead of 2, the required additional renewable electricity would be 25 % less for HPs in DH and 50 % less for building-wise HPs with high ambition level and a COP of 3 as shown in Tab. 3.

Table 3. Influence of COP of the HP on the electric energy demand w_{el} of the building stock (BS).

Scenario (SH + DHW demand in kWh/(m² a))	BAU (80 +20)	IMPROVE (55+20)	AMBITION (30 + 20)	BAU (80 +20)	IMPROVE (55+20)	AMBITION (30 + 20)
		Central			Decentral	
Rel. Loss of DH		10 %			-	
COP (conservative)		2			2	
W_{el} / kWh/(m² a)	55	41.25	27.5	50	37.5	25
COP (improved)		2.5			2.5	
W_{el} / kWh/(m² a)	44	33	22	40	30	20
ΔW_{el} / kWh/(m² a)	11	8.25	5.5	10	7.5	5
COP (depending on AL of BS)				2	2.5	3
W_{el} / kWh/(m² a)				50	30	16.7
ΔW_{el} / kWh/(m² a)				0	7.5	8.33

2.5. Combined Heat and Power

For gas and biomass fired combined heat and power plants (CHP) a CHP coefficient (power to heat ratio) of $\sigma = 1.0$ ($\eta_{el} = 0.4$, $\eta_{th} = 0.4$) is assumed. It is defined as the ratio between electricity generation (W_{el}) and thermal generation (Q_{th}):

$$\sigma = \frac{W_{el}}{Q_{th}} \quad (4)$$

The CO_2 emissions allocated to the electric energy and the thermal energy are evaluated using the Carnot Method. The Carnot-Efficiency η_C is calculated based on the maximum i.e. the flow temperature of the DH system (assumed to be 160°C) and the minimum temperature, i.e. the ambient temperature (10 °C):

$$\eta_C = 1 - \frac{T_{min}}{T_{max}} \quad (5)$$

The so-called fuel fraction of electrical and thermal energy can be calculated based on the thermal and electric efficiency and the Carnot efficiency.

Fuel fraction of electrical energy $A_{F,el}$:

$$A_{F,el} = \frac{(1 \cdot \eta_{el})}{\eta_{el} + \eta_C \cdot \eta_{th}} \quad (6)$$

Fuel fraction thermal energy $A_{F,th}$

$$A_{F,th} = \frac{(\eta_C \cdot \eta_{th})}{\eta_{el} + \eta_C \cdot \eta_{th}} \quad (7)$$

The CO_2 conversion factor is determined based on the fuel fraction and the thermal and electric efficiency.

$$f_{CO2,el} = A_{F,el} \cdot f_{CO2,gas} / \eta_{el} \quad (8)$$

$$f_{CO2,th} = A_{F,th} \cdot f_{CO2,gas} / \eta_{th} \quad (9)$$

CHP is assumed to be purely electricity driven.

2.6. CO_2 emissions

The total CO_2 emissions are determined based on the secondary energy (S-E) and the CO_2 conversion factors (eqs. (10) to (11)) and parameters in Table 4 with hy: hydro, wi: wind, PV: photovoltaic, bCHP-

E/bCHP-H: biomass CHP electricity and heat, fCHP-E/ fCHP-H: fossil CHP electricity and heat, waste/RE: waste heat, waste incineration, geo and solar thermal, W_{el}: electric energy, Q_{DH}: thermal energy and E: fuels

$$f_{CO_2,el} = \mathrm{f_{hy}} \cdot CO_{2,hy} + \mathrm{f_{wi}} \cdot CO_{2,wi} + \mathrm{f_{PV}} \cdot CO_{2,PV} + \mathrm{f_{bCHP}} \cdot CO_{2,bCHP-E} + \mathrm{f_{fCHP}} \cdot CO_{2,fCHP-E} \quad (10)$$

$$f_{CO_2,DH} = \mathrm{f_{waste/RE}} \cdot CO_{2,waste/RE} + \mathrm{f_{bCHP}} \cdot CO_{\mathrm{bCHP-H}} + \mathrm{f_{fCHP}} \cdot CO_{\mathrm{fCHP-H}} + \mathrm{f_{HP}} \cdot CO_{2,el} \quad (11)$$

$$CO_2 = \mathrm{W_{el}} \cdot f_{CO_2,el} + Q_{DH} \cdot f_{CO_2,DH} + E_{Bio} \cdot f_{CO_2,Bio} + E_{Gas} \cdot f_{CO_2,Gas} + E_{Oil} \cdot f_{CO_2,Oil} \quad (12)$$

Table 4. CO_2 emissions of fuels, electricity generation and DH sources based on [9].

	f_{CO2} / [g/kWh]	Remark		f_{CO2} / [g/kWh]	Remark
Fuel			Heat		
- Oil	310		- Waste-Heat	9	Incl. waste incineration
- Gas	247		- Geoth., ST	9	
- Biomass	17		- central HP	var.	El. mix
Electricity			- Fossil CHP	129	
- Fossil CHP	371	σ = 1	- Bio CHP	11	
- Bio CHP	32		- Fossil DHP	247	
- Hydro	1		- Bio DHP	17	
- Wind	5				
- PV	10				

3. Results and Discussion

3.1. Phase-out of Fossil

The phase-out of fossil fuels and the transition to renewable electricity and renewable DH is shown in Fig. 3. In spite of the high ambition level in the building sector (i.e. deep thermal renovation) and a high share of DH the electricity demand is increasing. A major part of the DH is covered by large-scale central HPs which contribute with a relevant share to the increase of the electricity demand. The additional electricity demand is covered by a large extent by PV and wind.

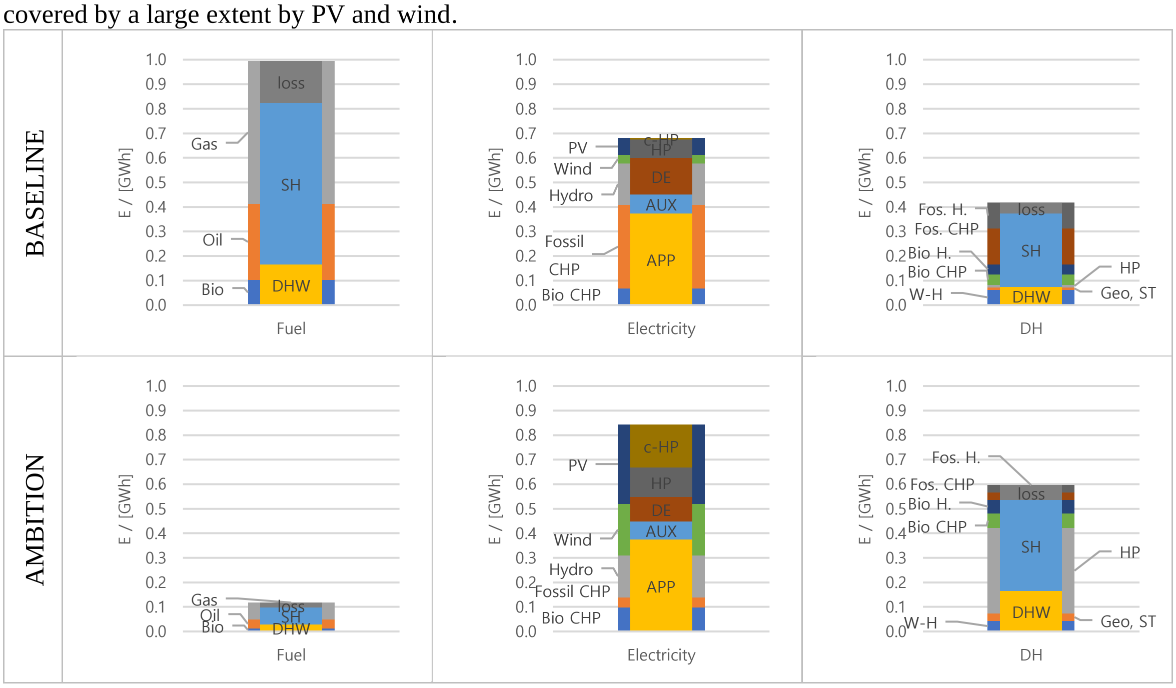
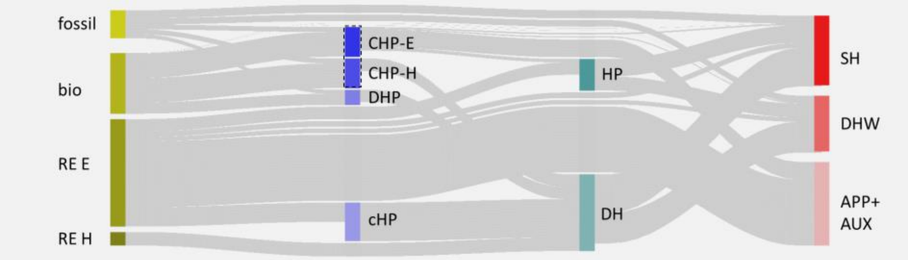


Fig. 3. Transition from fuel-based heating to HP and DH as well es decarbonization of electricity and DH from baseline to AMBITION level scenario.

3.2. Ambition Levels and influence of deep thermal renovation

Fig. 3a, b and c show exemplarily the Sankey diagram for the highest ambition level in terms of electricity and DH and three different ambition levels for the building stock (a: AMBITION, b: IMPROVE, c: BAU). The higher ambition level in the building stock leads to the lowest CO_2 emissions, and significantly reduced required amount of electricity for HPs (central and decentral) and this in consequence to a significantly reduced need to extent renewable electricity.



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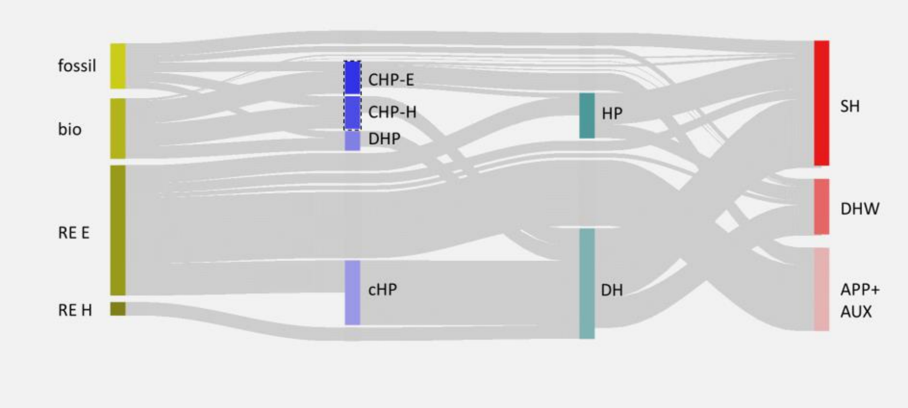

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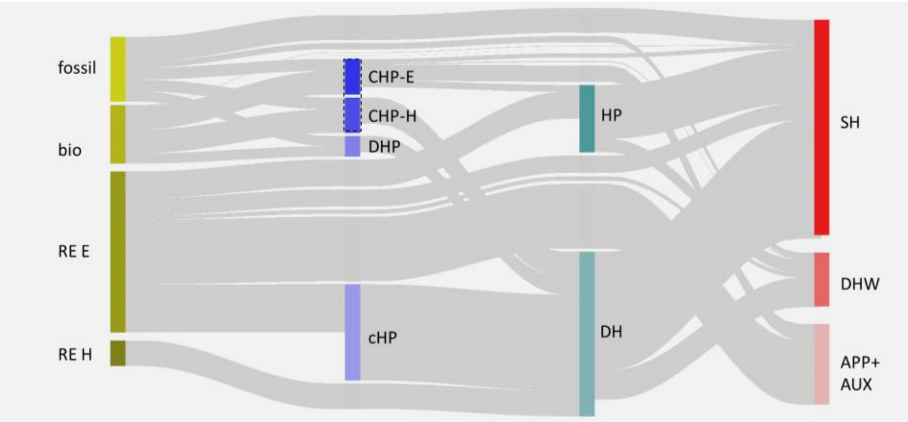


c

Fig. 4 Sankey diagram[1] of energy system case "AMBITION" with (a) deep thermal renovation (AMBITION), 41.9 ton CO_2 (b) thermal renovation (IMPROVE), 61.6 ton CO_2 and (c) no thermal renovation (BAU), 107.8 ton CO_2.

3.3. Decarbonization Strategies and Ambition Levels

The resulting development of the CO_2 emissions (Fig. 4a), the electricity (Fig. 4b) and the DH (Fig. 4c) demand as well as of the required extension of PV and wind (d) in the different decarbonization paths (see section 2.2) are summarized in the following diagrams. From Fig. 5 it can be derived that the HP-path leads to the overall lowest CO_2 emissions. However, the implementation of HPs in existing buildings is technically very challenging. It can be seen for all variants that without deep TR, switching from fossil to HP-based heating will significantly increase the energy consumption of the building stock. The mere phase-out of oil and gas is not sufficient to reduce the CO_2 emissions.

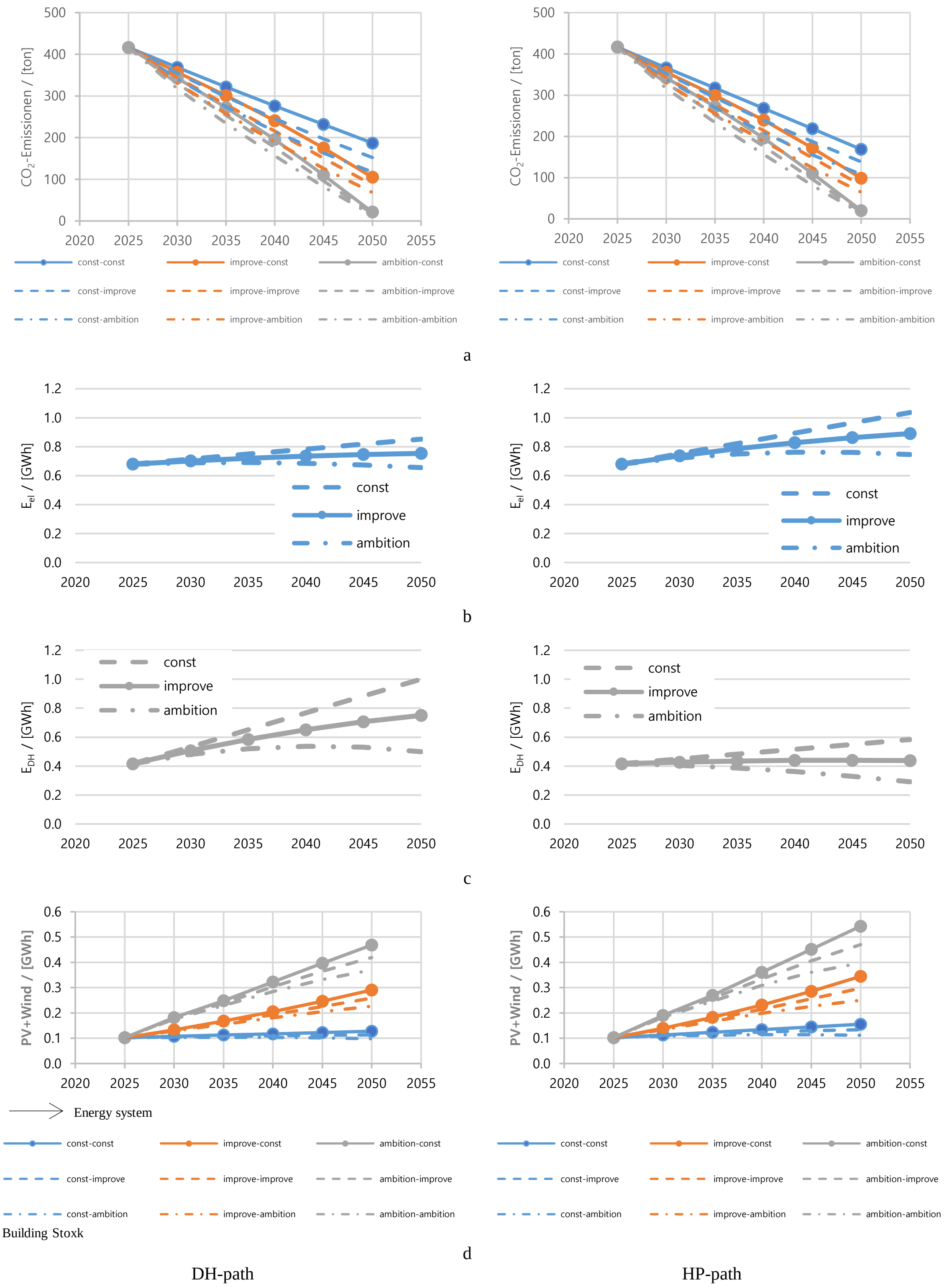
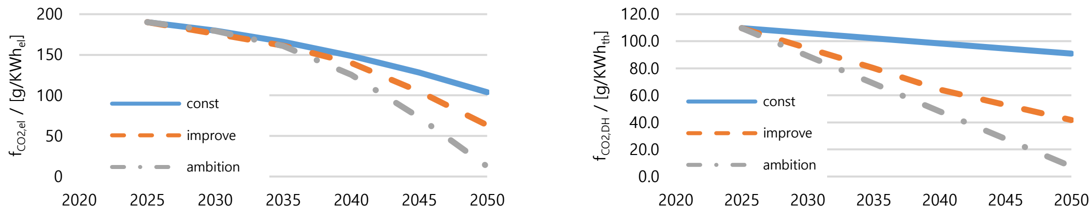


Fig. 5. Development of the annual CO_2 emissions (a), total electricity demand (b), DH demand (c) and extension of PV and wind electricity (d) according to the different paths (left: DH and right HP) and according to the different ambition levels of the building stock (legend: energy system AL – building stock AL).

The IMPROVE energy scenarios do not reach sufficient reduction of CO_2 emissions without ambitious renovation. Instead, in the AMBITIOUS energy scenario a diminishing influence of the ambition level in the BS can be seen, i.e. deep thermal renovation does not seem to change the picture. However, this goes on cost of a significantly extension of the electricity generation. Without high ambition level in the building sector, the AMBITION scenario in the energy sector can only be achieved by massive extension of PV and/or wind. This would lead to an increasing mismatch between winter and summer (winter gap, see section below). The DH-path requires a massive extension of DH grids with a large number of central HPs. As in all AMBITION scenarios (and to a lower extent also in the IMPROVE) the CO_2 conversion factor will relevantly decrease, CO_2 tax on electricity and DH will lose its relevance with proceeding time, as also shown in the next section.

3.4. Single Building Perspective

Based on the results of the scenario, the CO_2 emission on building level can be evaluated using conversion factors for electricity and in case DH. The resulting conversion factors are summarized in Fig 6.



Electricity: DH-path and HP-path DH: DH-path and HP-path

Fig. 6. Development of CO_2 conversion factor for electricity (left) and DH (right)

In all scenarios the conversion factor for electricity reduces. It reaches nearly zero in 2050 in case of high ambition level (12.4 g/kWh_{el}). The conversion factor of DH is connected to that of electricity (due to the central HPs) and also reduced to almost zero in 2050 in case of high ambition level (7.4 g/kWh_{th}).

For the building, if no regulations are supposed except phase-out of fossil for a given point of time, any measure or combination of measures could be chosen: DE, HP or if applicable DH

Additional measures are optional

- Thermal renovation (standard, deep)
- Onsite renewables (PV)

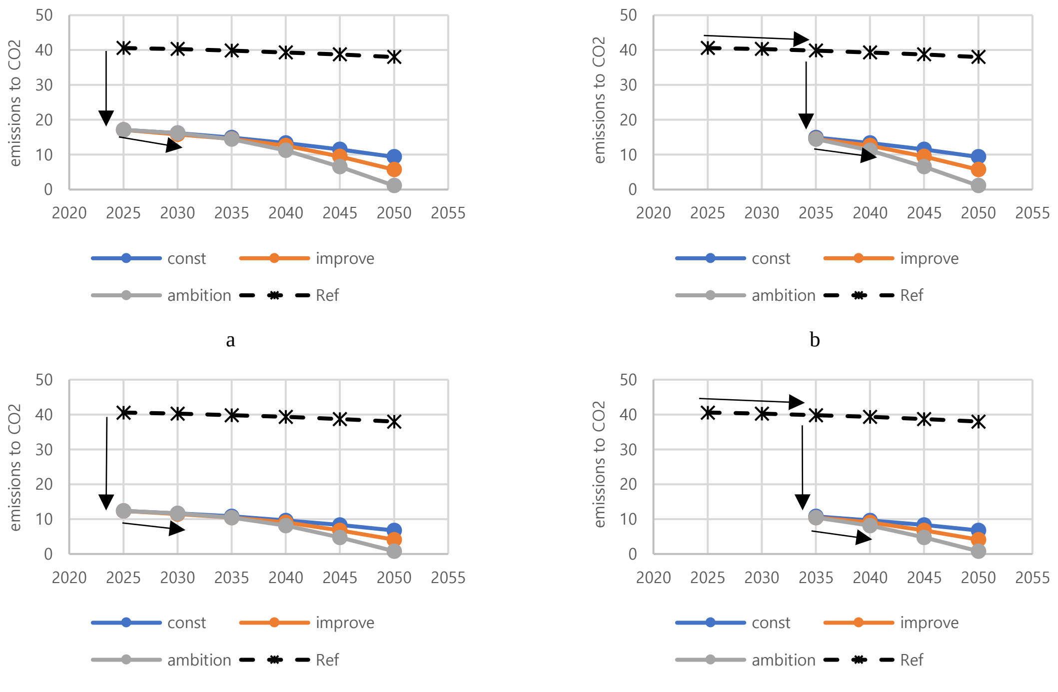


Fig. 7. Development of CO_2 emissions for a single building switching to HP (a in 2025 and b 2035) and optionally in combination with a deep thermal renovation (c in 2025 and d in 2035).

Assuming the building is equipped with a gas-boiler, and has the average characteristics as described in Table 1, the CO_2 emissions can be calculated for different combinations of measures and different points of time (i.e. switching from fossil-based heating to either DE or HP or DH in 2025, 2030, 2035, 2040). Here exemplarily, the results for a switch in 2025 and 2035 are shown. Independent of the point of time of the implementation of the measure, in 2050, the emissions are very low with respect to the baseline. The additional thermal renovation does not significantly influence the CO_2 emissions and even to a lower extent if the measure is implemented later. Hence, a CO_2 tax would, if switching from fossil-based heating to electricity-based, be of minor influence and would not trigger the additional thermal renovation.

3.5. Winter gap and seasonal storage

Additional electricity demand "generated" by means of insufficient efficiency measures (i.e. DE instead of HP, insufficiently or not renovated buildings) has to be provided by RE, i.e. by wind turbines or PV. While the main electricity demand occurs in winter (in particular in case of inefficient buildings), the contribution of PV (and also of hydro) will be available mainly in summer. Wind energy has a less seasonally pronounced characteristic but is volatile, too. If - as can be expected - the share of PV will be dominating because of higher public acceptance, there will be a strong seasonal mismatch between demand and supply. This seasonal gap (also called winter gap) requires (seasonal) storage capacities. To some extent pumped hydro storage may be available, but the main contribution will have to be covered by renewable hydrogen (and/or methane). The cycle efficiency of electrolysis-hydrogen-(mechanization)-storage and re-electrification (with fuel cell or gas turbine) is with optimistic assumptions in the range of 30 %. Consequently, for each kWh of electricity that has to be stored, 3.33 kWh have to be generated in summer at correspondingly very high costs.

3.6. Strategies

From the results of the scenarios, the following strategies for the building stock and energy policy can be derived:

- Develop a clear and transparent energy policy that includes the building stock as a major column;
- Evaluate measures in the building stock from the macro-economic instead of from the micro-economic perspective;
- Identify lock-in effects and avoid/prevent all measures that lead to lock-ins;
- Focus on energy efficiency in the building stock first, then renewables;
- Restrict direct electric heating (neither for SH nor for DHW);
- Set absolute limit for final energy for electricity (or heat in case of DH) for buildings;
- Direct fundings/subsidies in-line with the overall climate and energy policy goals. Cancel all contra-productive fundings/subsidies;
- Balance investments in the building sector with reduced need to invest in the energy system (PV, wind, energy storage);
- Develop a clear long-term strategy for the extension of DH and define dedicated districts;
- Set a CO_2 budget (per person) instead of a CO_2 long term target.

4. Conclusions

This increasing share of RE in future electricity and DH system will lead to a significant reduction of the CO_2 conversion factor for electricity with also a relevant influence on the CO_2 conversion factor of DH when HPs are involved. The dilemma is that in such a scenario, a high ambition level with respect to deep TR, or the further integration of onsite RE coupled to a HP will not significantly influence the CO_2 emissions of a building. Instead, a high ambition level on building level and massive onsite PV will be required to reach the goal of the phase-out of fossil energy. This requires an energy policy approach instead of market initiatives, and for example e.g. CO_2 budgets or other limits and conditions will have to be defined. This dilemma can only be solved if the building sector is seen as part of the energy policy.

Insufficient ambition goals on building level lead to the so-called lock-in, which prevents or delays reaching the climate goals on energy system level. A purely micro-economic focused approach will inevitably lead to fail. The building stock has to be considered as a part of the energy system and planning and implementation of any measure has to be evaluated in the context of the transition to a sustainable (and affordable) energy system. A CO_2 budget (per person) until e.g. 2050 (better 2040) instead of target of CO_2 emissions in 2050 (or

2040) is required. Transparent and reliable goals have to be set for the building sector with limits for the final energy consumption instead of non-directed incentives.

As outlook, an economic analysis should be performed as a next step and also the need of (seasonal) energy storage should be considered in future works.

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Nomenclature

AL	Ambition Level	H	Heat
BAU	Business as usual	HP	Heat Pump
BS	Building Stock	HVAC	Heating, ventilation and air conditioning
CHP	Combined heat and power	MFH	Multi-family house
CHP-E	Combined heat and power electricity	MVHR	Mechanical ventilation with heat recovery
CHP-H	Combined heat and power heat	nZEB	Nearly zero energy building
cHP	Central heat pump	NZEB	Net zero energy building
COP	Coefficient of performance	PEB	Positive energy building
DE	Direct electricity	PED	Positive energy district
D-E	Delivered energy	RE	Renewable energy
DH	District heating	SFH	Single-family house
DHP	District heating plant	SH	Space heating
DHW	Domestic hot water	SPF	Seasonal performance factor
E	Electricity	S-E	Secondary energy
ETS	Emissions trading system	TR	Thermal renovation
GHG	Greenhouse gas	U-E	Useful energy

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