The role of storage in the Swiss energy transition

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Abstract:

The transition towards more sustainable, fossil-free energy systems is interlinked with a high penetration of stochastic renewables, such as wind and solar. In this context, energy storage technologies of different kinds - namely electrical, thermal and chemical - are commonly expected to play a major role; however, this role is seldom quantified using whole energy system models. In this paper, our goal is to assess and quantify the role of these different storage technologies in low carbon energy systems. To do this, we apply EnergyScope TD, a novel open-source energy planning model, to the real case study of the national energy system of Switzerland; concretely, we optimise the Swiss energy system for a target future year with an hourly resolution. The results indicate the following trends: (i) Thermal storage in combination with heat pumping becomes the main source of flexibility in the electricity sector; (ii) electrification allows a high penetration of renewables in the transportation sector, and the remaining share of mobility is supplied by synthetic fuels; (iii) a mix of storage technologies is needed for different applications at different timescales, such as synthetic fuels for long-term and for mobility demand, and thermal storage for short term (day-week) and for heat demand. Overall, it emerges that storage technologies - such as thermal storage, vehicle to grid and synthetic fuel storage – can help decrease cost, decarbonise the mobility and heating sectors, and reduce dependency on fossil fuels.

Keywords:

Energy system, Energy storage, Energy transition, Switzerland, Renewable energy.

1. Introduction

In 1972, the book “The Limits to Growth” was released with a message still valid today: "The earth’s interlocking resources – the global system of nature in which we all live – probably cannot support present rates of economic and population growth much beyond the year 2100, if that long, even with advanced technology” [1]. This statement has been corroborated by the latest report by the Intergovernmental Panel on Climate Change (IPCC), which illustrates the negative impacts of a temperature increase above 1.5°C compared to pre-industrial levels [2]. While it is widely accepted that an “energy transition” is urgently needed [16], it is often unclear what would be the best scenarios to reach the set targets. When defining scenarios towards sustainability, we are limited by our own biases and ideas. In this context, energy models can be of help by providing a quantitative and objective basis for discussion.

Phasing-out fossil fuels with renewable energies (REs) (such as wind, solar, hydro, geothermal and biomass) represents an urgent necessity. To reach this objective, solar and wind have, in most countries, the largest potential. Historically, energy systems flexibility was ensured by fossil fuels, which are widely available and cheap to store; by replacing them with these "stochastic" renewables, a lack of flexibility is foreseen and thus storage technologies emerge as the potential actor to balance the system. However, most of the studies analyzing energy storage either (i) focus only on the electricity sector considering a limited set of technologies [3,4] or (ii) perform simulations instead of optimising the entire energy system [5,6].

In our study, we use EnergyScope TD[1], a novel open source energy planning model [7]. The model optimizes both the investments and the operation of the entire energy system accounting for all the energy flows within its boundaries, including electricity, mobility and heating.

Using this model applied to the Swiss energy system (building on previous studies [8-14]), we aim at identifying and quantifying the role of the different energy storage technologies - namely electrical, thermal and chemical - and their synergies for the decarbonization of the country. Concretely, we implement a scenario from the Joint Activity Scenarios and Modelling (JASM) project [14] for Switzerland. This scenario under development and called the climate policy scenario (CLI), is driven by a political commitment of meeting the targets of the Paris Agreements to keep the increase of temperatures below 1.5°C by the end of the century compared to pre-industrial levels.

The paper is structured as follows: in Section 2, we present the energy model used and the case study; in Section 3, we analyze the energy transition with a strong focus on storage technologies. An in-depth analysis of a high RE share scenario highlights the role and benefit of each technology and how to reach this target. Finally, in Section 4, we analyze the main trends in the results and we calculate the cost of storage. In particular, we show that the electrification of mobility and heat is a key to increase the share of REs and efficient technologies in the energy system. Additionally, a mix of storage technologies, including vehicle-to-grid, thermal storage, synthetic fuel and electrical storage, becomes necessary to keep a flexible system while still ensuring affordable energy costs.

2. Methodology

In this paper, we use the open-source energy model EnergyScope TD [7], which is a linear programming (LP) model. EnergyScope TD is an energy system model representing with the same level of detail the heating, mobility and electricity sectors. Its main features are: (i) satisfying the system end-use demand, accounting for electricity, heat and transport; (ii) optimizing both the design of the system and the operation while minimising its overall cost; (iii) an hourly resolution which makes the model suitable to analyze the integration of intermittent REs; (v) its mathematical formulation which offers a low computational cost thanks to a method resorting on typical days (TDs).

Hereafter, we briefly introduce the energy model, highlighting the changes made for this work. Then the case study is described with a particular focus on the energy storage technologies.

2.1. Energy system modelling

As proposed in [7] and illustrated in Figure 1, an energy model is composed of three parts: resources, demand, and energy conversion technologies. Resources include all the importable and extractable resources. In this illustrative example, resources are solar energy, electricity and natural gas (NG). The energy demand includes electricity, high and low temperature heat, public and private passenger mobility, and freight transport by rail or road. The energy conversion system lies in between resources

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[1] The code is available at https://github.com/energyscope/EnergyScope/tree/Limpens_Role_2019_code

and demand, using energy conversion technologies to transform resources into useful energy services. The energy conversion system is composed of layers and technologies. Layers are defined as all the elements in the system that need to be balanced in each period. They include resources and end use demand (EUD). For example, the power grid must be balanced at each time period, hence the sum of imports, production and storage discharge must equal the sum of consumption, grid losses and storage charge. Another example taken from Figure 1 is the gas layer, where imports must equal the consumption by gas combined heat and power (CHP) and compressed NG (CNG) cars. Finally, technologies can connect layers together, such as a heat pumps connecting the electricity layer to the low temperature heat layer. Technologies include storage and infrastructure. This latter includes the power or district heating network (DHN) grids.

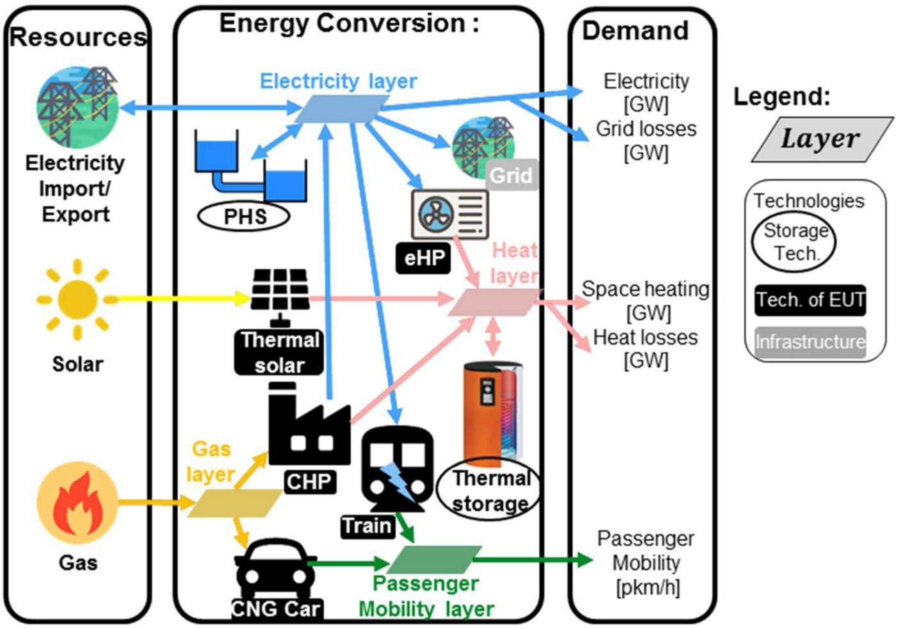

Figure 1. Conceptual example of an energy system based on the Energyscope TD modelling approch. Abbreviations: pumped hydro storage (PHS), electrical heat pump (eHP), combined heat and power (CHP), compressed natural gas (CNG).

2.2. Changes for the present work

In the literature, various studies indicate power-to-gas (PtG) as a promising technology [4-6]. Most of them include hydrogen and methanation (i.e. production of CH_4 from H_2 and CO_2). However, the sources of CO_2 required for the methanation are rarely taken into account, and thus CO_2 availability could become an issue in a society with low CO_2 emissions. In this work, we integrate a non-exhaustive list of CO_2 resources. To do this, we make three changes compared to the model proposed in [7]: (i) CO_2 layers are added in order to model the CO_2 inputs for methanation; (ii) new truck technologies are added for freight transport; (iii) fuel storage is added. Figure 2 represents how the CO_2 sector is modeled together with the aforementioned changes.

2.2.1. CO_2 and related technologies

As shown in Figure 2, we assume two sources of CO_2: air and the cement industries, each one related to its layer. From these sources, the CO_2 can be captured to be used at a later stage. Hence, there are two carbon capture technologies: from the air (CC_air) and from the cement industry (CC_cement). Both of them provide carbon captured to the “CO_2 captured” layer. This latter has a CO_2 storage and can provide CO_2 to the synthetic methanation technology.

2.2.2 Road freight

In the model version in [7], road freight used exclusively diesel trucks. To phase out fossil fuels, we add two additional technologies that can resort to synthetic fuels: compressed natural gas (CNG) trucks and fuel cells (FC) trucks. The first uses natural gas in an internal combustion engine and the second uses hydrogen in a FC.

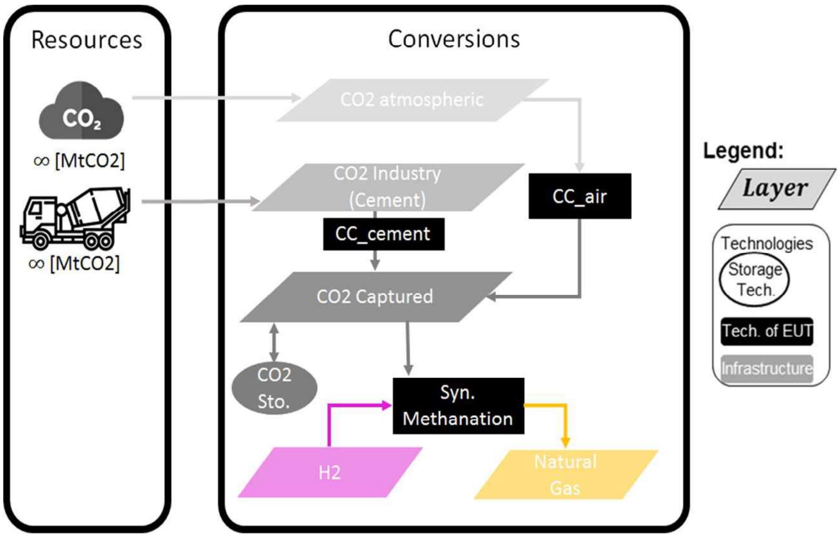

Figure 2. Visual representation of the CO_2 *layers.* CO_2 *from the atmosphere (air) and from cement industries can be sequestrated and stored in a* CO_2 *storage. This sequestered* CO_2 *is usable for methanation. Abbreviation: carbon capture and storage (CCS).*

2.2.3 Synthetic fuels and storage

In systems with very high shares of renewables, promising technologies, such as PtG or gasification, are necessary to provide energy during periods of deficit. As an example, during summer electricity peaks, electrolysers can absorb the excess of electricity and produce hydrogen. This hydrogen can be transformed to methane and stored. We have implemented two technologies producing synthetic fuels from renewable resources: hydrogen from electrolysis and synthetic natural gas (SNG) which can be used similarly to natural gas. SNG can be produced by biomass gasification or hydrogen methanation.

2.3 Case study

The model is applied to the Swiss energy system, as also done in [7]. Figure 3 shows the extended perimeter of the model with the changes described in the previous section.

As seen in Figure 3, we account for 21 storage technologies related to electricity, heat and fuels. These storage technologies are presented in Figure 4, grouped by sector and time scale, and their technical characteristics are summarised in Table 2. The three groups are electricity storage, thermal storage and synthetic fuel storage. The first group, electricity storage, includes vehicle to grid (V2G), batteries, pumped hydro storage (PHS) and hydro dams. The dams do not directly store electricity, but they can buffer the production and are indirectly associated to an electrical storage. Batteries and V2G are used for short-term applications. Instead, hydro dams are expected to behave as today, i.e. to shift the summer water inflow for higher electricity production in winter. In between, PHS might also shift excess of production from one day to another. The second group, thermal storage, includes decentralized daily storage, centralised daily storage and centralised seasonal storage technologies. The latter is expected to store heat from summer to winter. The third group is synthetic fuel storage grouping hydrogen storage and natural gas storage.

2.4 Performance indicators

In this work, we use as performance indicators the system total cost, the RE share and the CO_2 emissions. The system cost is defined as the sum of the annualized investment cost of technologies, the operating and maintenance costs of technologies and the operating costs of the resources.

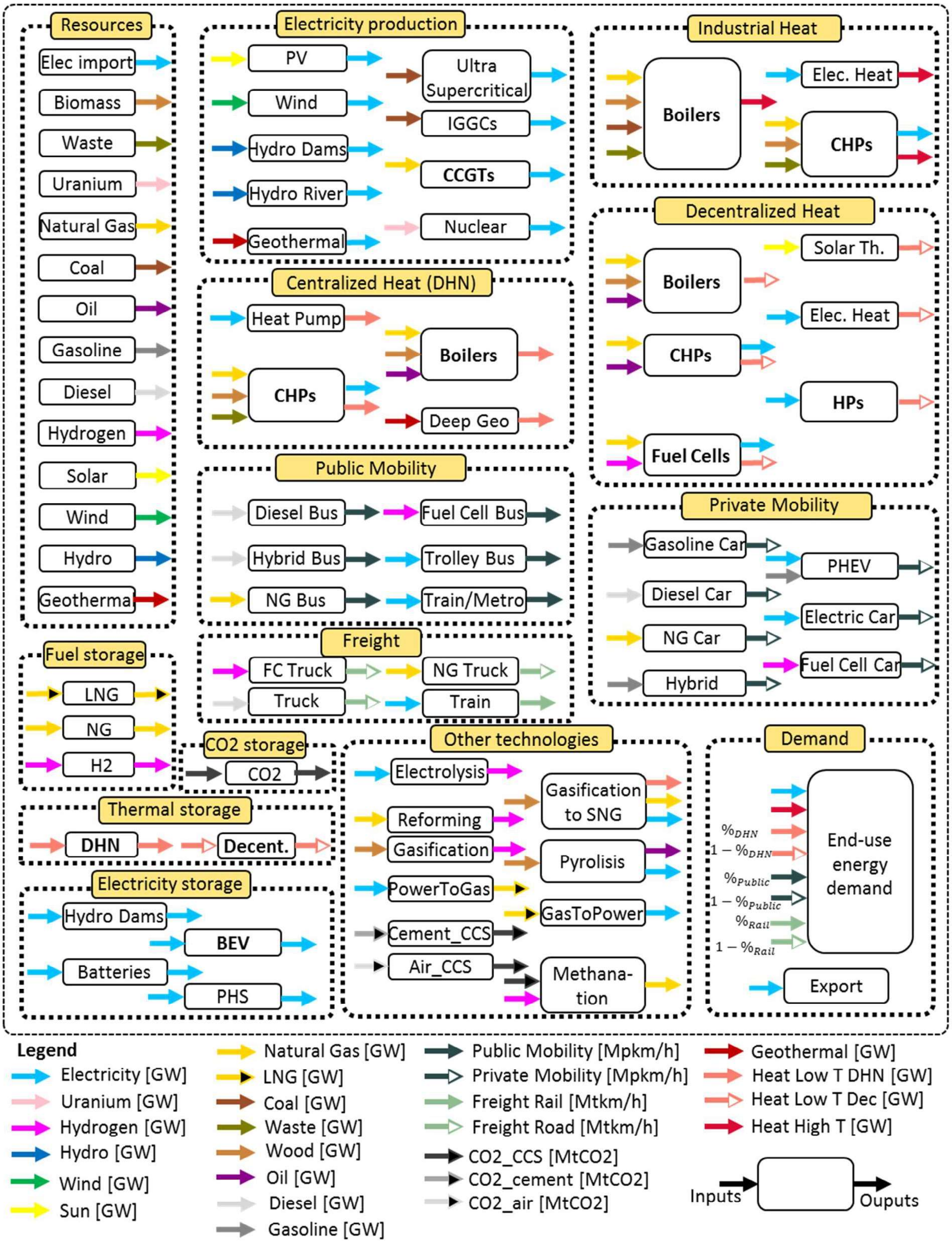

Figure 3. Application of the LP modelling framework to the Swiss energy system. ***Bold*** *technologies represent groups of technologies with different energy inputs (e.g. Boilers include gas boilers, oil boilers ...).* ***Decent****. represents the group of thermal storage for each decentralised heat production technology. Abbreviations: photovoltaic (PV), integrated gasi_cation natural gas combined cycle (IGCC), natural gas combined cycle (CCGT), combined heat and power (CHP), heat pump (HP), natural gas (NG), liqui_ed natural gas (LNG), plug-in hybrid electric vehicle (PHEV), district heating network (DHN), battery electric vehicle (BEV), pumped hydro storage (PHS).*

Table 2. Storage characteristics. Abbreviations: investment (inv.), maintenance (maint.), efficiency (η), storage (sto)

Resource	inv. cost	maint. cost	$\eta_{sto,in}$	$\eta_{sto,out}$	$\%_{sto,loss}$
Units	$[CHF_{2015}$/kWh]	$[CHF_{2015}$/kWh/y]	[-]	[-]	$[s^{-1}]$
Li-on batt.	1000^c	0^a	0.95^b	0.95^b	2e-4^b
EV batt	0	0^a	0.95^b	0.95^b	2e-4^b
PHS	100^c	0^a	0.9^b	0.9^b	0
TS dec.	20.26^b	0^a	1	1	82e-4^b
TS cen. daily	3.36^b	0^a	1	1	4.2e-5^b
TS cen. seas.	10.13^b	0^a	1	1	7.5e-4^b
Hydrogen sto.	1^c	0^a	1	0.7^d	0
CH_4 sto.	1^c	0^a	1	0.95^d	5e-5^d

[a]: Investment and maintenance cost merged.

[b]: From [7], batteries for EV are assumed the same as Li-on.

[c]: From [14].

[d]: From [15].

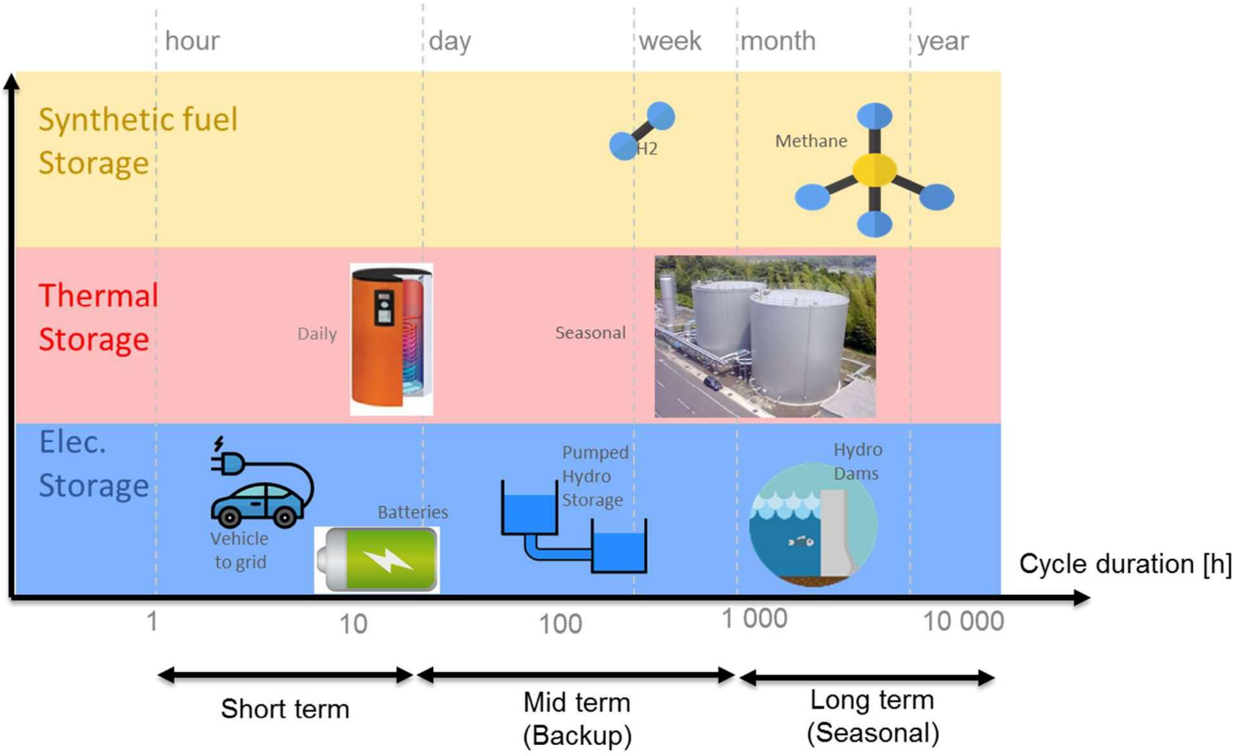

Figure 4. Overview of the storage technologies sorted by sector and timescale.

The RE share is defined as the ratio between the energy supplied by RE and the total primary energy consumption. The renewable primary energy consumption is considered equal to the energy output by the corresponding technologies, except for biomass, where the primary energy contained in biomass is considered. As an example, if PV produces 1 TWh_e, we account for 1 TWh of solar primary energy. Instead, if 1 TWh of heat is produced by a biomass boiler (with a 86% efficiency), then we account for 1/0.86 TWh of biomass primary energy.

The calculation of CO_2 is based on the direct emissions from resources. Table 3 summarizes the CO_2 emissions for each resource. Resources not present in the table, such as biomass, geothermal, etc. are assumed to have no CO_2 emissions.

Table 3. Direct CO_2 *emissions for resources.*

Resource	CO_2 emissions [kg CO_2/kWh]
Elec. Import	0.200
Gasoline	0.266
Diesel	0.266
Light Fuel Oil	0.266
Coal	0.401
Uranium	0.004
Waste	0.160

3. Results

In this section, we first analyze the transition pathway, detailing how the primary energy supply changes as a reduction in CO_2 emissions is gradually imposed; then, we focus on an in-depth analysis of the CO_2 optimal scenario. Third, the trade-off between cost and CO_2 emissions of the energy system is assessed by means of a Pareto analysis. In particular, we show when each technology appears in the system. Finally, we study the optimal storage technologies mix in this energy transition.

The following results are obtained while resorting to 12 typical days (TDs) as suggested in [7]. The energy transition is forced by imposing a reduction in CO_2 emissions, starting from a reference situation of 35 MtCO_2/y, corresponding to the Swiss CO_2 emissions in 2015.

3.1. Primary energy needs

Figure 5 shows how the primary energy consumption decreases as we impose a reduction of CO_2 emissions in the system. Indeed, the energy transition is associated with a reduction of primary energy used. In the first (high emissions) scenario, the system needs almost 183 TWh of primary energy. This amount is reduced to 137 TWh at 10 MtCO_2/y and slightly increases at lower CO_2 emissions. This primary energy reduction is achieved thanks to the integration of more efficient technologies. We define a technology “efficient” if it consumes less primary energy for a similar or improved service than a traditional technology, such as an electric vehicle which consumes less electricity for mobility than a traditional gasoline car, or a HP which consumes less primary energy than a boiler to supply the same quantity of heat. The plateau observed at emission levels around 10 MtCO_2/y represents the minimum primary energy required, as the full potential of efficient technologies (heat pumps, DHN, trains, CHP and BEV) has been exploited. At lower CO_2 emissions, the system relies more on storage technologies to provide flexibility to the system. This extra capacity implies energy losses, which explain the small increase in primary energy consumption.

Additionally, Figure 5 shows the electricity sector (stripes) compared to the rest (heating and mobility, plain), and the RE integration (green). We observe a direct correlation between reducing CO_2 emissions, increasing the RE share and the electrification of the system. The electricity sector is the first one to achieve a high share of RE. Then, electrification through technologies such as electric vehicles, trains or heat pumps… allows heat and mobility sectors to use electricity from renewable sources. Additionally, limited RE resources can also be integrated in the heat and mobility sectors. In our work, the renewable resources for heat supply are geothermal, biomass and thermal solar. Geothermal appears as a promising resource (mostly for direct heating) and starts to be used once CO_2 emissions are lower than 25 Mt. Thermal solar does not appear as a promising technology for two reasons. First, it has a negative correlation with heat demand. Indeed, when there is strong irradiation, heat demand is usually low. Second, thermal solar needs to be backed up during lack of sun, which is normally done by fossil fuel boilers.

Once the system shifts to heat pumps and combined heat and power, the lack of flexibility makes thermal storage profitable. At lower CO_2 emissions than 10 Mt/y, biomass is used in boilers for industrial heating. The electricity end use demand plus the grid losses remain more or less constant during the transition. Hence, the exceeding part of electricity represents the electrification of the other sectors. We observe that most of the final renewable energy consumed in heat and mobility sectors comes from the electrification.

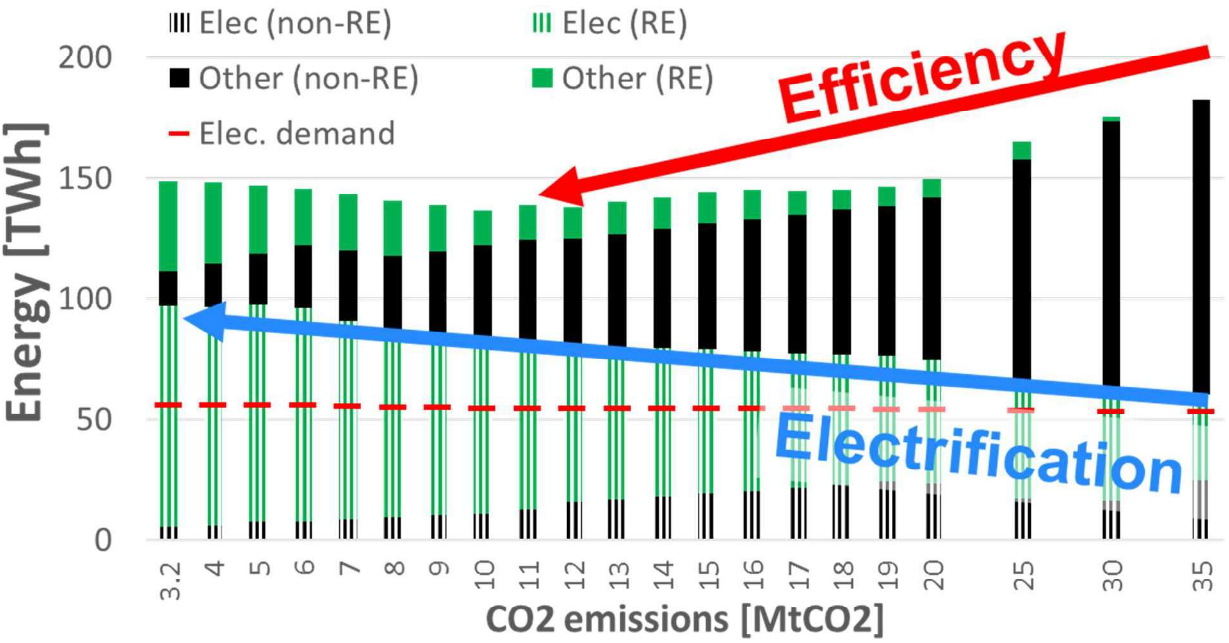

Figure 5. Primary energy consumed per year for different scenarios of the energy transition.

At the optimal CO_2 emissions (3.2 $MtCO_2$), only the municipal solid waste, later called waste, still emits CO_2. The latter has a high fossil component, such as plastics. Waste is valorised during winter in district heating network (DHN) through CHPs and also used in industrial boilers for high temperature heat generation. In this study, waste CHP units supply a minimum share of 20% of DHN heat.

3.2. CO2 optimal scenario

As an illustrative example, we propose an in-depth analysis of the CO_2 optimal scenario. As this scenario relies on a high share of intermittent RE (solar PV 30.0% and wind 2.6%), it requires the highest amount of flexibility from storage technologies.

The CO_2 optimal scenario emits 3.2 Mt CO_2/y for a global cost of 16.9 billion CHF_2015/y[2]. These emissions correspond to the waste reaching its minimum share (20 TWh/y). Figure 6 represents the entire energy conversion chain, from primary energy (left) to final energy consumption (right). The system consumes 148.8 TWh of primary energy out of which 128.8 TWh is from RE resources.

In total, 69% of the primary RE produced is electricity. The rest of primary RE (31%) is used for combined generation through CHPs, centralised heating and industrial heating. The amount of RE electricity produced exceeds the total electricity demand which is 53% of the electricity ($53\%_e$), including grid losses ($7\%_e$). The rest is used for power to heat (PtH), power to mobility and synthetic fuels production using hydrogen.

PtH uses $18.7\%_e$ of the total electricity to satisfy 55% of the heat demand ($55\%_{th}$) through heat pumps ($14.3\%_e$) or to directly produce high temperature heat for industry ($4.4\%_e$). The remaining demand of heat ($45\%_{th}$) is provided by geothermal power ($15.9\%_{th}$), CHPs (biomass $6.7\%_{th}$, waste $4.0\%_{th}$), boilers (biomass $2.0\%_{th}$ and waste $14.9\%_{th}$) and as a by-product of biomass gasification ($1.5\%_{th}$).

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[2] Not accounting for emissions related to construction of vehicles for mobility.

Power to mobility uses $12.9\%_e$ to directly satisfy mobility. Here, we make a distinction with direct use, such as train or electric vehicles (EVs) and indirect, such as synthetic fuels used in traditional cars. Direct power to mobility satisfies public transportation ($4.4\%_e$), private transportation ($6.8\%_e$) and freight by trains ($1.7\%_e$).

The last part of the electricity ($15.4\%_e$) is transformed into synthetic fuels.

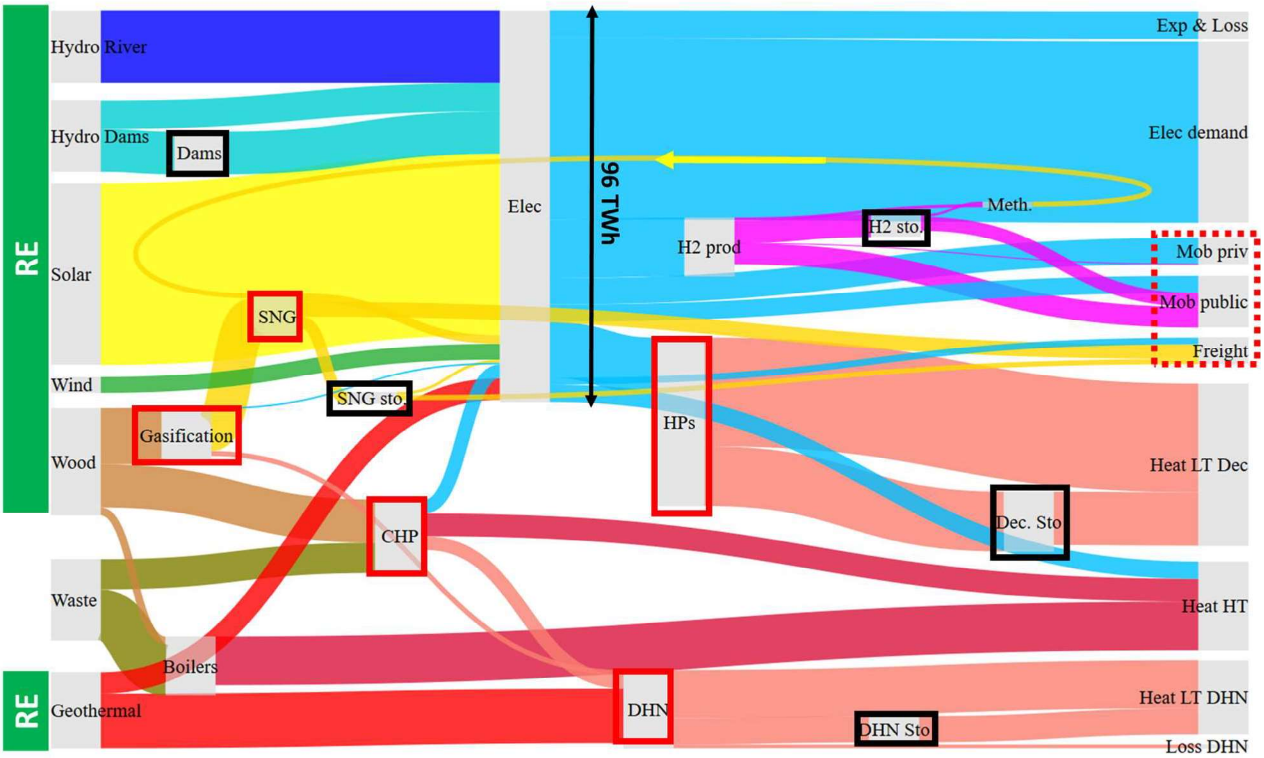

Figure 6. Energy flows in the CO_2 *optimal scenario. Primary energy (left part) is 87% RE (green). More efficient and storage technologies are framed in red and black, respectively. Dotted lines mean that the technology does it partially, such as Freight where only the electrical part (trains) is efficient. A loop is made between methanation from hydrogen and synthetic natural gas (SNG).*

In order to reach high shares of RE, the system relies on storage technologies and more specifically on synthetic fuels. The latters are mostly produced during periods of excess production, stored and used during periods of energy deficit. For example, during sunny days, the excess of electricity is absorbed by electrolysers and transformed to hydrogen. This hydrogen is partially used for public transportation (86.3%) or transformed to methane (14.4%) through the methanation process. Storage shifts 48.6% of the hydrogen. Additionally, biomass gasification is used to provide a constant production of SNG.

Synthetic fuels are expensive to produce but cheap to store. Hence, the optimum is to minimize their use. In this case, they are used to supply flexibility to the power grid through combined cycle gas turbines (CCGTs). Mobility sectors use as much renewable electricity as possible, thanks to technologies such as trains, trams and electric vehicles (EV). However, power to mobility cannot answer all the mobility demand and synthetic fuels supplies the remaining part. This last uses a mix of hydrogen fuel cells (FC) technologies and natural gas (NG) technologies for public mobility and freight. FCs are more efficient but the hydrogen storage losses are high. Hence, their share is limited by the availability of the hydrogen produced and the rest is provided by SNG technologies.

3.3 Pareto equilibrium and integration of technologies

The cost optimal solution for the energy transition can be analyzed through a Pareto frontier graph. As LP problems have only one objective, the total annual cost of the energy system and the CO_2 emissions can be alternatively used as objectives to minimise. Else, the two objectives can be combined using the ε-constraint method [17]. This method seeks trade-off solutions by formulating a bi-objective problem in which one of the objectives is minimized, and the other is constrained by an upper value ε, which is made vary parametrically. As a result, the pareto frontier graphs represents for each targeted CO_2 emissions, the cost optimal system.

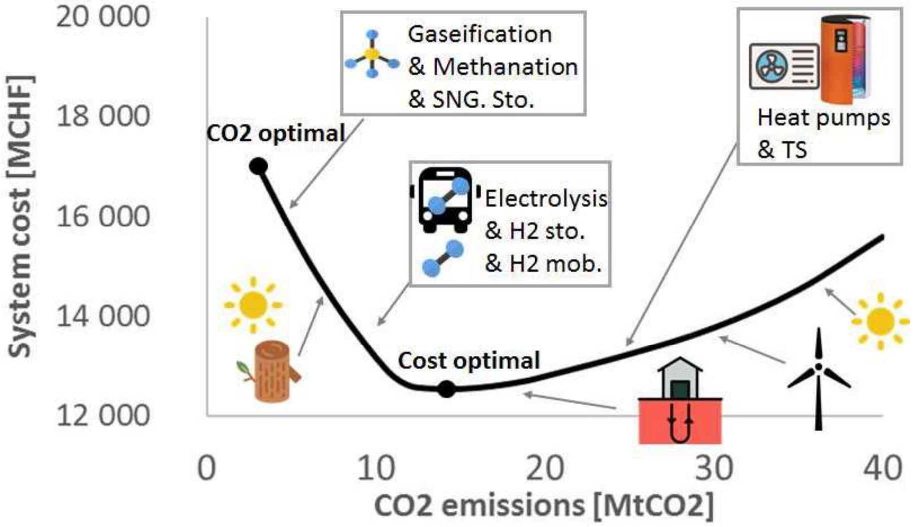

Figure 7. Cost – CO_2 *emissions optima. From right to left, new technologies and resources are integrated as illustrated. Abbreviations: thermal storage (TS), hydrogen (*H_2*), synthetic natural gas (SNG.), storage (sto.).*

Figure 7 illustrates the system cost evolution during the energy transition. At first, the overall cost decreases. On the one hand, using less primary energy results in a lower cost for the resources which reduces the system OPEX. On the other hand, more efficient technologies are often more capital-intensive which leads to an increase in CAPEX. However, the balance results in a lower total cost. This decrease is mainly achieved by the electrification of the heating sector through heat pumps. In parallel, the following renewable resources start to be installed: photovoltaic (PV), wind and geothermal. Electricity produced by wind and geothermal has a limited potential of maximum of 3.91 TWh and 0.527 TWh, respectively.

The cost optimal solution relies on cheap NG to provide flexibility to the system. At lower CO_2 emissions, NG is phased-out and the system has to compensate this loss of flexibility by other resources, such as PV, biomass and geothermal for electricity, but also new technologies, which are synthetic fuels, fuel cells or NG mobility and storage. Consequently, the price of the system increases.

3.4. Storage mix

The energy system needs storage technologies to: (i) provide flexibility; (ii) shift excess from one period to another; (iii) downsize some installations. As an example, the massive integration of PV results in a need of flexibility at night (i) and shifts the summer excesses to winter (ii).

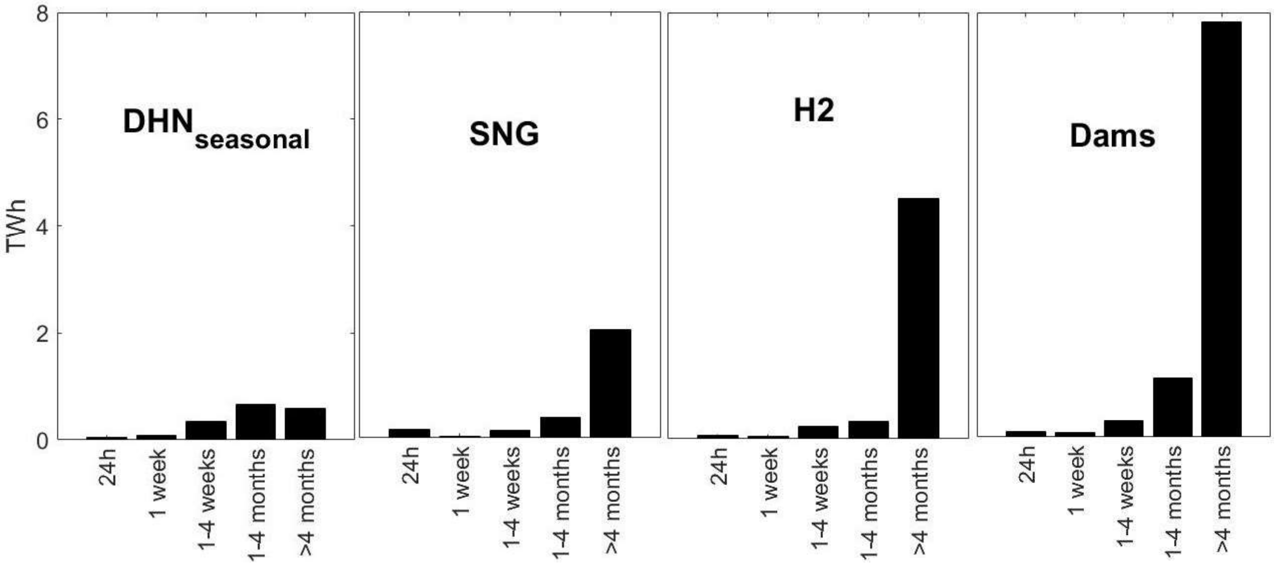

Figure 8. Energy stored for different technologies and timescales.

As previously illustrated, the optima are based on a mix of storage for different applications at different timescales. Figure 8 shows, for the CO_2 optimal scenario, the energy stored for different cycles length for the long term storage technologies. Energy is stored for periods longer than a month in hydro dams (8.9 TWh), hydrogen storage (4.8 TWh) and SNG storage (2.4 TWh). Complementary to these technologies, seasonal thermal storage stores 1.7 TWh for shorter periods, from a week to some months. Finally, at a daily scale, thermal storage shifts 19.4 TWh of heat, mostly for decentralised heat pumps, and 1.87 TWh is smart charged by vehicle to grid. CO_2 storage is for a non-energy application: it is used to downsize the carbon capture units and stores up to 0.3 $MtCO_2$.

Figure 9 illustrates the impact of removing storage technologies on the system cost. Without synthetic fuel storage, the system oversizes biomass gasification and electrolysers capacities to fit the SNG and hydrogen peak demands resulting in an additional cost without energy savings. Similarly, without thermal storage, the system oversizes the thermal production capacity and reaches the heat peak demand. Moreover, part of the centralised heat pumps are replaced by biomass boilers to reduce the power to heat demand. Without both thermal storage and synthetic fuels storage, the two negative impacts are summed. Without Dam storage, an additional capacity of PV is required to compensate the lack of hydro electricity produced. This substitution by intermittent RE implies additional difficulties for the power system. To face this problem, NG is used in gas CHPs and additional CCGT capacities to supply flexible electricity. At low CO_2, the NG is synthetically produced at a high cost. As an example, The SNG required for the CO_2 optimal with and without dams are 3.7 and 16.4 TWh, respectively.

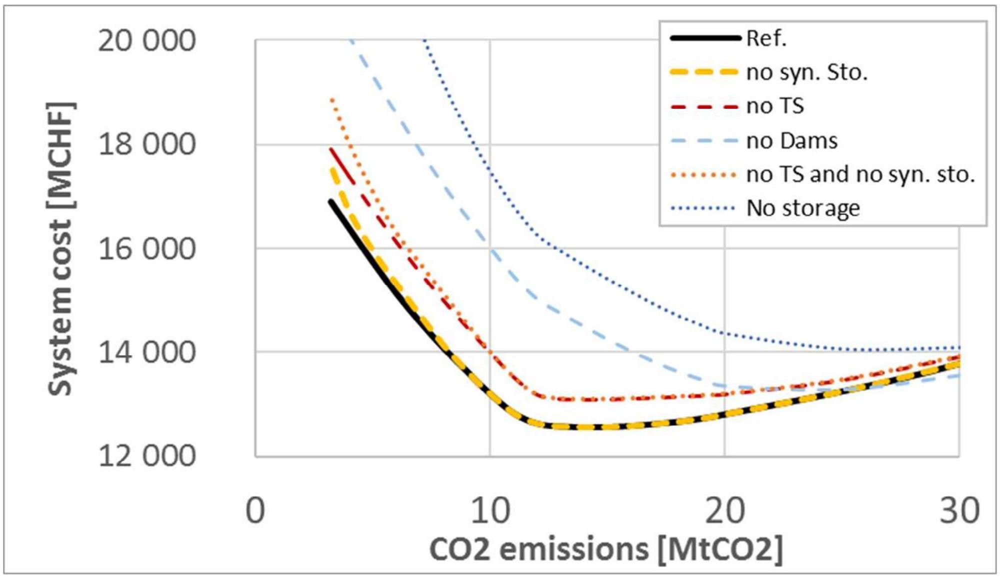

Figure 9. Pareto front for different configurations without storage. Abbreviations :Reference scenario (Ref), synthetic storage (syn. Sto.) and thermal storage (TS).

4. Discussion

The energy transition relies on four pillars: electrification, efficiency, renewable energies and storage technologies. In a first step, integration of renewable energies in parallel with energy efficiency and electrification lower the CO_2 emissions. In a second step, a need of additional flexibility arises due to the integration of intermittent renewable energies, storage technologies and electrolysers are deployed. The flexibility of the power system is first achieved through hydro dams and power-to-heat which behaves as a flexible electricity demand. Indeed, heat pumps associated with thermal storage can act as a buffer at a daily scale but also at a week scale. In a third step, the phase-out of fossil fuels is achieved by using synthetic fuels for mobility and power sector flexibility. Additionally, synthetic fuel storage is used to shift the excess production of summer to the winter.

From a cost perspective, the first step implements more expensive technologies which are less energy intensive, the overall balance results in a lower system cost and reaches a cost optimum where 52% of primary energy is supplied by RE.

Thermal storage appears as the most used storage technology as it stores 21.1 TWh (48.6%) compared to 10.6 TWh (24.4%) for hydro dams, 10.0 TWh (23.0%) for synthetic fuels and 1.7 TWh (3.9%) for V2G. The analysis reported in Table 4 explains this abundant use of thermal storage.

Table 4. Cost of stored energy. The cost of synthetic fuels production includes the cost of electricity production[3] and storage. The cost of hydro dams is proportionally based on the overall cost of dams.

	Technology	Cost [CHF/MWh]
Heat	Daily den.	1.6
	Daily cen.	3.9
	Seas. cen.	28.0
Electricity	Hydro dams	64.1
Synthetic fuels Production	Electrolysis	150.3
	Methanation	167.0
	Gasification	167.4

It summarizes the cost of the different storage technologies compared to the cost of production of synthetic fuels including storage. Thermal storage technologies appear as the cheapest way to store energy. Daily thermal storage technologies perform more cycles and thus have a lower cost than seasonal thermal storage.

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[3] We assume that the electricity consumed exclusively come from PV.

A last consideration is made about the CO_2 required for synthetic methanation. For the CO_2 optimal case, it consumes 0.3 $MtCO_2$ to produce 1.3TWh of SNG. It is lower than the cement emissions, 1.5$MtCO_2$, in Switzerland in 2015[4].

5. Conclusion

We have applied the EnergyScope TD model to the Swiss energy system[5]. The energy model optimises the investment and hourly operation of the Swiss energy system accounting for all the energy flows within its boundaries. The model has been applied to study the Swiss energy transition according to a climate policy scenario driven by a political commitment of meeting the targets of the Paris Agreements to keep the increase of temperatures below 1.5°C by the end of the century compared to pre-industrial levels.

Results define the optimal storage mix and quantify each technologies, including thermal storage, vehicle to grid and synthetic fuels. Thermal storage (TS) emerges as the most important technology as it stores almost 50% of the stored energy in a low CO_2 emissions scenario. Indeed, by combining TS with electrical heat pumps, it can buffer the electricity demand and support the power grid.

This study highlights the key role of electrification, efficiency, renewable energies and storage technologies in the energy transition.

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