Democratization of energy production and a possible future of autonomous supply of individual households in Switzerland

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Abstract

The availability of energy is a key element of modern civilization. Households require energy for heating and the operation of technical appliances. To date, the generation and provision of energy is largely in the hands of large commercial or state-owned energy suppliers. While this system allows for economies of scale and global resource networks, it puts the individual at a disadvantage, left without influence on pricing, sourcing, or secure provision. By investigating technical, geographical, financial, political, and environmental aspects, this study elucidates whether households can become more independent or even autonomous in the near future, by generating their own heating and electrical energy.

Based on the collected information from public sources and energy suppliers, the energy consumption and needs of households are determined. This is put in perspective to the energy production by current providers and compared to realistic near-future household production capacities. The analysis shows that technically, households can autonomously generate sufficient overall energy to become energy independent. There are however practical challenges. The geographic location of Zurich makes photovoltaic energy production during winter months inefficient, exactly when most electricity is needed to power heat exchange systems. In the absence of longer-term high capacity energy storage solutions, the peak electricity demand cannot be covered without overall non-economical and space-intensive installations. Further, current limitations at the regulatory level hinder the installation of capacities in protected areas, for which alternative non-decentralized solutions for sustainable energy provisions are being sought.

In summary, while the technologies for an autonomous energy supply of individual households are already available, the specific limitations of Zurich as a densely populated city currently prohibit a general achieving of this goal. However, with future improvements in energy efficiency and the implementation of new regulations and incentives supporting more installations, within a few decades the goal will be achievable.

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I. Introduction

A. Motivation for the study and relevance of the topic

The production and abundant availability of energy in various formats are hallmarks of modern civilization and the backbone of the economies and political systems in industrialized countries. The respective importance is illustrated at the level of global interactions and global change also in the IB Syllabus[1,2]. From this, it becomes evident that access to energy is crucial not only for economies and countries, but also for the individual. As with politics, equal access is best achieved via a democratic system, with the process leading to it being called democratization. Access to energy today is largely ruled by market conditions and governmental regulations. Democratizing energy is not only a matter of economic and social impact, but also a central strategic element in the age of global climate change[3].

To increase the direct influence of individuals and small communities on the energy system, the production of energy needs to transition from the large players of industry and politics to a democratic system where everyone has the chance to participate. This democratization of energy production leads to an energy production system that is spread more widely among a diverse range of participants, including individuals, small businesses, and communities[4]. In this system, various actors, often at a grassroots level, can generate, store, and share energy, thereby contributing to the overall energy mix[5].

The fundament for democratizing energy lies in its decentralization. Energy production and storage is dispersed across various locations, so-called Distributed Energy Resources (DERs), instead of being concentrated in large, centralized plants and grids. DERs may include solar panels, wind turbines, and energy storage units like batteries that can be deployed in local contexts including individual households.

While individual households themselves do not consume energy at the scale of the industrial or governmental sectors, their combined consumption accounts for a significant fraction of the overall energy demand. With this, private households, either directly or indirectly, play an important role for economic, environmental, and political considerations of energy supply. While the energy supply at the global or national level cannot be easily changed from today's system and replaced by alternative technologies in the short term, at the level of the individual household, new options for sustainable and renewable energy production do exist. Households generating energy autonomously may even have the option of becoming independent from external energy sources and suppliers.

The above considerations have motivated me for the present study: allowing everyone to participate in a democratic and fair system, increasing the sustainability of our economy, addressing climate change through pragmatic actions in daily life, and sparking new developments by benefitting from technological progress, would be goals to achieve.

B. Research goal, hypothesis, and scope of research

The goal of the present research report is to elucidate the research question:

What are the technical options and chances of feasibility regarding the democratization of energy production and a future autonomous supply of individual households in Zurich, Switzerland.

On the example of an average Swiss household in the city of Zurich, the current demand for energy supply for the most central aspects of daily life are investigated and evaluated whether they can be met by autonomous energy production using today's technologies.

The research hypothesis of the work is that a democratization of the energy production and a future of autonomous energy supply of an individual household in Zurich, Switzerland can be achieved.

Considered will be energy used for heating and cooling, for the preparation and storage of food, for the preparation of hot water, the consumption of electrical power for other home appliances and electrical devices. Energy used for individual mobility using battery electrical vehicles, will be included to the extent possible. Energy consumed by private households indirectly, e.g., for public transport, airplane transport, vacation activities, eating out, etc. will not be considered in these calculations, as will be indirect energy amounts used to produce and distribute the products used by the households, also known as grey energy.

II. Research

Methodology and information sources

To collect information and data on the research topic, various sources were used. Statistical data on energy production and energy consumption was collected from public resources[6,7,8,9,10]. For background information on the topic, the scientific review literature, and literature from energy suppliers and environmental organizations were consulted. For technical details, information materials of suppliers of the respective technologies were used. For political strategy, policy and regulatory information, publicly accessible resources were consulted[11]. The combination of all information and data was discussed with experts in the field.

A. Energy consumption of individual households in Switzerland

1. General aspects of energy consumption

In Switzerland, energy consumption by private households is dominated by its alpine climate and the high level of industrialization and development of the civil society. Heating demand, especially during winter, is significant and mostly covered by fossil fuels. For powering appliances, lighting, electronics, and air conditioning, electricity is the primary energy source. The households display an interest in energy-efficient appliances and Swiss building codes are stringent, emphasizing high insulation standards and energy-efficient designs.

2. National energy consumption according to sources and use categories

The national end energy[a] consumption is dominated by fossil fuels, followed by electricity and gas. (Table 1 and Figure 1). Consumption from renewable and other sustainable energy sources accounts for only a minor fraction.[9]

Table 1 Sources of end energy consumption in Switzerland 2022 (all users, not only households).
Source: Bundesamt für Energie, Gesamtenergiestatistik 2022 [9].

Energy source	Fraction (%)	Energy source	Fraction (%)	Energy source	Fraction (%)
Oil products	45.4	Coal	0.5	Biogenic fuels	0.9
Petroleum fuels	11.9	Wood energy	5.4	Biogas	0.2
Propellants	33.5	District heating	2.8	Solar	0.3
Electricity	26.8	Industrial waste	1.6	Environmental heat	2.7
Gas	13.3				

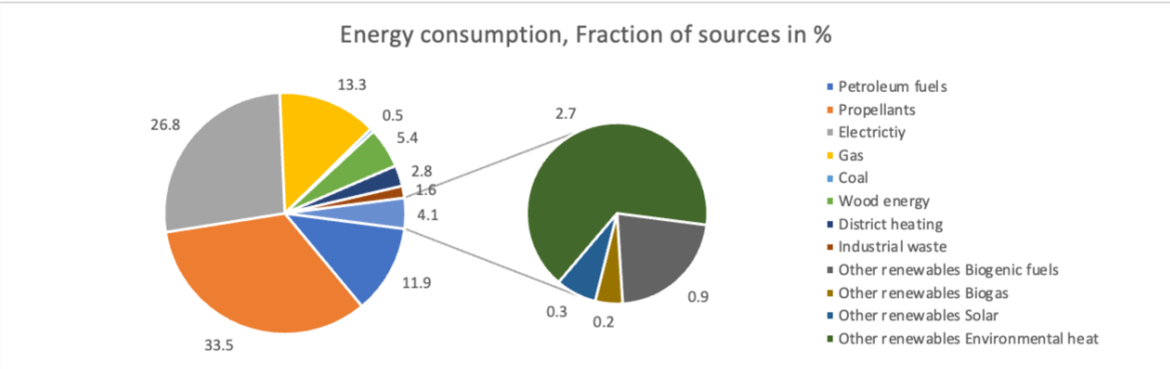


Figure 1 Sources of end energy consumption in Switzerland 2022 (own figure).
Source: Bundesamt für Energie, Gesamtenergiestatistik 2022 [9].

[a] End energy = energy purchased or produced by the consumer for a specific use without transmission and distribution losses or the energy sector's own consumption.

3. Consumption of energy by households

Of the total energy consumed in Switzerland, private households account for 27%[9] (Table 2 and Figure 2). Compared to the overall national consumption, private households show a different energy mix (Table 3).

Table 2 Energy consumption in Switzerland 2022, according to users.
Source: Bundesamt für Energie, Gesamtenergiestatistik 2022 [9].
* Total considering statistical deviation including agricultural sector.

Energy consumer	Fraction (%)
Private households	27.6
Industry	19.0
Services	16.0
Traffic / mobility	36.2
Total national consumption	100.0*

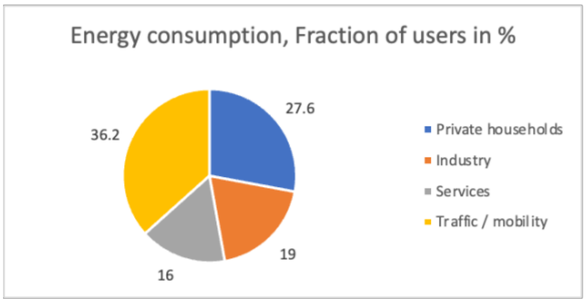


Figure 2 Energy consumption in Switzerland 2022, according to users (own figure).
Source: Bundesamt für Energie, Gesamtenergiestatistik 2022 [9].

To enable an evaluation of the usefulness and impact of DERs, the end energy mix used by Swiss households is reported in more detail in Table 3. All energy consumption and production numbers have been converted from original units to Watt hours (GWh, respectively).

Table 3: End energy mix 2022 of private households in Switzerland.
Calculated from: Source Bundesamt für Energie, Gesamtenergiestatistik 2022 [9] (1 GWh = 3.6 TJ).

Energy source	Consumption (TJ) 2022	Consumption (GWh) 2022	Consumption (%) of total[#]	Addressed by DERs
Oil products (heating)	**51'320**	**14'255**	**24%**	Yes
Electricity household	**69'680**	**19'355**	**33%**	Yes
Gas	**45'550**	**12'653**	**22%**	Yes
Coal	50	14	<0.1%	Yes
Wood energy	17'140	4'761	8%	Yes
District heat	**8'520**	**2'367**	**4%**	Yes
Other renewables	19'050	5'292	9%	Yes
Total households	211'310	58'697	100%	

Energy consumption in Zurich

The mix of consumed energy in Zurich is not very different from the national average with around one third coming from electricity and two thirds from primarily fossil sources.[10] Due to the higher settlement density and the more extensive infrastructure like gas lines and district heating, some sources differ from the national average.

Table 4 Energy mix in Zurich (all user groups), latest numbers available used.

Source: Stadt Zürich, www.stadt-zuerich.ch[10].

End energy source	2020 (GWh)	2020 (%)
Oil	**793**	**9.4**
Kerosene	457	5.4
Diesel	851	10.0
Gasoline	346	4.1
Electricity	**2'875**	**33.9**
Electricity Wood and Waste	73	0.9
Electricity Solar and Wind	202	2.4
Electricity Hydropower	1'959	23.1
Electricity Nuclear	0	0.0
Electricity Europe (Import)	642	7.6
Natural Gas	**1'858**	**21.9**
District Heating	**717**	**8.5**
Wood, Envir. Heat, Biogas, Solar Collectors	**579**	**6.8**
Total	8'475	100.0

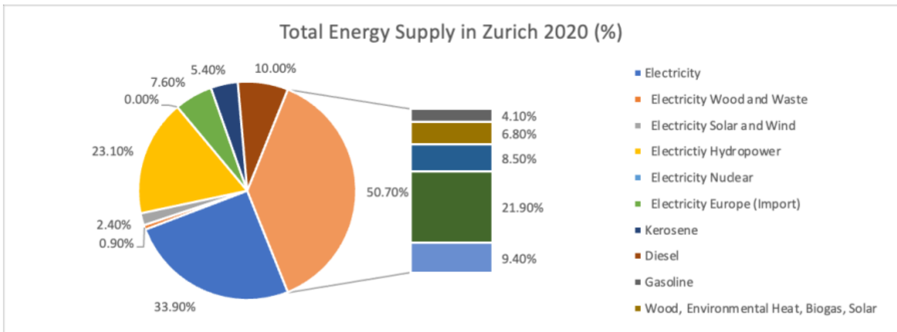


Figure 3 Energy mix in Zurich (all user groups) (own figure).

Source: Stadt Zürich, www.stadt-zuerich.ch[10].

Structure of households in Zurich and average energy consumption per household

In 2022, the average household size in Zurich was 2.01 persons per household, living in 209'050 households.[12] This compares to the national average of 2.21 persons living in 3.92 Mio households.[13] Excluding traffic and industry, the average local consumption per energy source can be calculated by adjusting the national average by local household numbers and sizes.

Table 5 End energy mix calculated per household in Zurich.

Mean values calculated from: Sources Bundesamt für Statistik, Gesamtenergiestatistik 2022[9], Stadt Zürich www.stadt-zuerich.ch[10], Statistik Stadt Zürich www.stadt-zuerich.ch[12], Bundesamt für Statistik www.bfs.admin.ch[13].

End energy source	2022 (kWh)	2022 (%)
Heating (sum of below)	**9'125**	67%
Oil	3'308	24%
Gas	2'936	22%
Wood energy and other renewables	2'332	17%
District heat	549	4%
Electricity	**4'491**	33%
Total	**13'615**	100%

For electrical energy consumed in Zurich, energy averages of the regional supplier EKZ (Canton of Zurich) can be used[14] and combined with numbers at the national level to get a measure for comparability between local and national consumption. Compared to equivalent data from the Federal Energy Department (BFE), minimal differences result from households that use electricity for heating and hot water production nationally.[15][16] When adjusting for mean vs. median differences, averaged median numbers can be generated (Table 6) for further use.

Table 6 Annual average household electrical energy consumption at the level of the Canton of Zurich (EKZ) and Switzerland (BFE) in kWh.

Median values calculated from: Sources Elektrizitätswerk des Kantons Zürich www.ekz.ch[14] and EnergieSchweiz Stromverbrauch eines typischen Haushalts 2021[15].

Building type	**Apartments**				**Single Family Homes**	
Number of persons per household	**1**	**2**	**3**	**4+**	**1-2**	**3+(EKZ) 4 (BFE)**
EKZ: Low consumption	600	1'100	1'500	1'800	2'000	3'000
EKZ: Intermediate consumption	1'300	2'000	2'500	3'100	3'500	5'000
EKZ: High consumption	2'200	3'300	4'300	5'200	5'000	7'000
BFE: Typical consumption		2190	2650	3110		4058
Averaged Medians	1'367	**2'148**	2'738	3'303	**3'500**	4'765

⇒ The averaged medians calculated in Table 6, for a 2-person household in an apartment building and single family home, respectively, will serve as the basis for the further research into whether the current demand for electrical energy for an average household in Zurich, can be generated by decentralized energy resources at the household level.

The numbers for heating energy are similarly broad ranging for different household forms and sizes. When comparing the average-based numbers of the end energy raw data sources with square meter-based numbers that reflect the building quality, the impact of high-consuming old buildings becomes evident. Based on the average living space of 39.6 m^2 per person[17] and 2.01 persons per household in Zurich 2022, reference numbers for the local heating demand can be calculated in relation to the building quality (Table 7).

Table 7 Energy demand for heating per household in Zurich, based on consumption average per square meter, weighted according to the building age (reflecting energy efficiency).

Sources energie.ch AG www.energie.ch[18] and Stadt Zürich www.stadt-zuerich.ch [19].

Calculation of building-specific heating demand per m² and household (per year)	A. Heating demand* kWh /m²	B. Building volume** m³	C. Fraction building category (estimate)	D. Subfraction building category (estimate)	E. Weight building category (B x D / B_{Total})	F. Heating demand weighted kWh/ average m² (A x E)	G. Persons in household x m2/person	H. Average household consumption kWh
Old buildings non-renovated	120	$151*10^6$	80%	5%	3.80%	4.6	2.01x39.6	9'552
Old buildings renovated	60			95%	72.60%	43.6	2.01x39.6	4'776
New buildings non-Minergie	40	$46*10^6$	20%	64%	15.00%	6	2.01x39.6	3'184
New buildings Minergie	20			***36%	8.60%	1.7	2.01x39.6	1'592
Total		$197*10^6$	100%	200% old and new	100% all buildings			
Average heating energy in kWh weighted per m2						56		
Average heating energy in kWh weighted according to building quality per household								**4'776**

* Source energie.ch AG www.energie.ch[18], ** Source Stadt Zürich Präsidialdepartement www.stadt-zuerich.ch[19], *** Source Stadt Zürich Präsidialdepartement www.stadt-zuerich.ch[20].

⇒ The heating energy calculated in Table 7, for a 2-person household in an average quality building, will serve as the basis for the further research into whether the current demand for heating energy for an average household in Zurich, can be generated by decentralized energy resources at the household level.

B. Current centralized energy production and provision

Switzerland's energy mix is strongly dependent on the country's geographical location and natural resources. Hydropower: Switzerland's mountainous terrain and numerous rivers make it ideal for hydropower generation, which accounts for most of the electricity generation. Nuclear Power: Nuclear energy is a considerable part of Switzerland's electricity generation mix but is planned to phase out by not replacing existing plants once they reach the end of their operational lifespan. Natural Gas and Oil: These are all imported and mainly used for heating and transportation. Renewable Energies (excluding hydropower): Includes solar, wind, biomass, and geothermal energy. Among these, solar has seen the most significant growth, but its share is still small compared to hydropower. Wind energy plays only a minor role in Switzerland, due to a lack of exposed open land and constant wind conditions. Electricity imports: Switzerland imports electricity during winter months when domestic demand exceeds production.

1. Centralized domestic energy production and provision

Energy production and provision at the national level

While Switzerland has no natural resources and hence no own fossil energy sources, several major producers of electrical energy and utility companies provide energy supply, encompassing electricity generation from hydropower, nuclear (material imported and converted domestically), and an increasing share of renewables.

Table 8 Domestic energy production according to sources.
Source Bundesamt für Statistik www.bfs.admin.ch[21].

Production Source	2022 (%)
Hydropower	61.5
Renewables	7.7
Fossil fuels	1.9
Nuclear energy*	28.9
Total	100.0

* Fuel imported and converted domestically

Energy production and provision at the local level in Zurich

For the City of Zurich, the Elektrizitätswerke der Stadt Zürich (EWZ) is the relevant supplier of electrical energy.[22] For the generation of electricity, EWZ has installed powerplants in Switzerland and abroad (wind energy mainly in Germany).

Table 9 Capacity of EWZ-own powerplant capacity according to sources.
Source Geschäftsbericht EWZ 2022[22].

Production Capacity	2022 (MW)
Hydropower	1'009.0
Wind energy	331.0
Solar	23.6
Biomass	3.8
Total	1367.4

C. Decentralized energy production options at the level of households

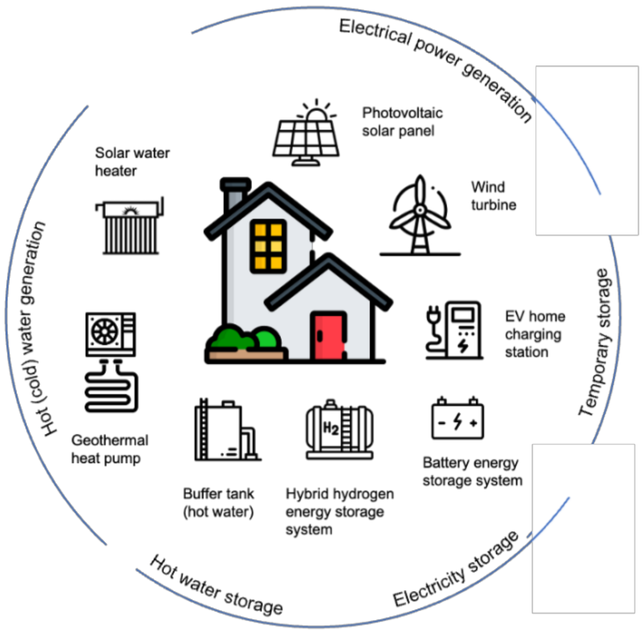


Figure 4 Technologies for decentralized energy production and storage (own figure).

Source: icons from https://www.flaticon.com.

1. Solar energy

Solar irradiation is the central factor for suitability. The irradiation is influenced by the geographical location as well as the orientation, inclination, and shading. The ideal roof orientation for energy generation for a solar energy systems is to the south, but a deviation to the south-east or south-west reduces the energy yield only to a limited extent.

Solar water heaters

Solar heat can be used for the purpose of warm water generation only, or in combination with heating support.[23] By heating water that is circulating in tubes by solar irradiation year round, per m^2 of installation, 300 to 600 kWh of heat energy can be generated per year. Using 5 m^2 and an average 2'200 kWh per year, 50% of the warm water and 20% of the heating energy can be covered by a solar heater area of 5 m^2 per household[24]. Precondition for higher heating efficiency is a large buffer storage as the warm water production is lowest during the winter heating period. Total cost of a combined system amounts to 15'000 CHF.

Photovoltaic solar panels

A solar cell or photovoltaic cell (PV cell) converts solar energy into electricity by using the photovoltaic effect. By illuminating the front of the solar cell, an electrical voltage is created between the front and back of the cell. Per kW of power, a PV system generates about 1'000 kWh of electricity per year. In relation to the average household size, 30 m^2 of roof area would be suitable for a 5 kWp (Kilowatt-Peak) installation, delivering up to 5'000 kWh per year. Total cost amount to 10'000 to 20'000 CHF, depending on installed total capacity.[25] Increasingly popular are plug-and-play systems that need no professional installation but are also usually not compatible with storage systems. Their output is in the 200-500 kWh p.a. range and only cover a small part of the electrical energy need.[26]

2. Heat pumps

Heat pumps collect heat from the environment (air, groundwater, or earth) for heating or hot water production. A refrigerant is pumped through a pipe system and the thermal energy is extracted from the environment through a heat exchanger, which heats the refrigerant by a few degrees and makes it gaseous. By reversing the process, heat pumps can also be used to cool a building.[27][28] The Coefficient of Performance (COP) refers to the ratio of thermal power output to electrical power input.

Air-Source Heat Pump (ASHP)

ASHPs are also called air-to-water heat pumps that extract heat from the ambient air. They are easy to install with little regulatory effort and can be mounted per individual household. Their efficiency is lower than the Ground-Source or Geothermal Heat Pumps (GSHPs), but the initial cost is also much lower. The space consumption is very small, amounting to about 1 m^2, but there is a certain level of noise immissions. Modern ASHPs have a COP of 3.5 and higher. For the generation of 5'000 kWh of heating energy, a system consumes around 1'400 kWh of electricity and costs about 6'000 CHF. ASHPs do not work below -20°C outside air temperature. For extreme weather, alternative or additional systems must be used.[29]

Ground-Source or Geothermal Heat Pump (GSHP):

GSHPs extract heat from the ground. Because ground temperatures are more stable than air temperatures, GSHPs are often more efficient than ASHPs, with a COP of approx. 5.2 for mixed warm water and heating purposes and work also at extreme temperatures to heat or cool buildings.[30] Most efficient deep-drilled geothermal probe systems consume less than 1'000 kWh of electricity for the generation of 5'000 kWh of heating energy and cost about 20'000 CHF. Apart from the higher efficiency but also higher investment costs, GSHPs underlie more complex approval procedures as they can interfere with ground water protection regulations.

3. Wind turbines

The advantage of a small wind turbine is its productivity in autumn and winter when solar power is inefficient and during the night when solar power is non-existent. Most free-standing private wind turbines have a rated output of up to approximately 5 kW,[31] roof-mounted turbines only around 1 kW. More than with photovoltaic systems, the annual electricity generation depends on the technology but also on the often changing wind supply. On average, a turbine with a capacity of 5 kW can generate between 2,500 and 10,000 kWh of electricity per year, with a very high yield only possible in a free-standing location near the coast or on a mountain range. Minimal wind speeds would need to be around 4 m/s to achieve reasonable productivity.[32] Total costs including construction for a private wind turbine amounts to between 2'000 and 6'000 CHF per kilowatt of power, or an average of approximately 20'000 CHF for a turbine with a capacity of 5 kilowatts.

D. Decentralized energy storage and buffering

1. Buffer tanks

Combination storage tank. It has a double-chamber system that heats and stores drinking and heating water separately and has less heat loss due to its small surface area. For an average household considered here, a volume of 500 l is assumed sufficient and would cost 15'000 CHF[23]. With this, smaller households dispose of a storage capacity of 25 kWh.[33]

2. Batteries

To store electricity for later use increases the overall efficiency of photovoltaic systems. Various energy storage systems are available, amongst which Lithium-Ion (Li-Ion) batteries are the most used.[34] Storage capacities of 5 kWh per household can be considered adequate, for which costs of about 3'000 CHF are calculated.

3. Hybrid hydrogen storages

Chemical energy storage exhibits lower storage capacity costs for long-term seasonal storage and higher storage density than batteries.[35] At present, the respective storage systems are still very expensive, but for the future, they provide much higher capacities at an expected cost reduced by 80%.[36]

4. Battery electrical vehicles (BEVs)

Modern electric cars often have so-called vehicle-to-load (V2L) or even vehicle-to-grid (V2G) capabilities. As they store their energy in large Li-Ion batteries of up to 100 kWh, they can serve as "free-of-charge" electricity buffers, as the approximately 30'000 CHF in battery costs are already included in the vehicle price.

E. Boundary conditions for decentralized energy production and storage

The feasibility and sustainability of DERs depend on geographical and political boundary conditions. Indicated in Figure 5 are a selection of relevant factors.

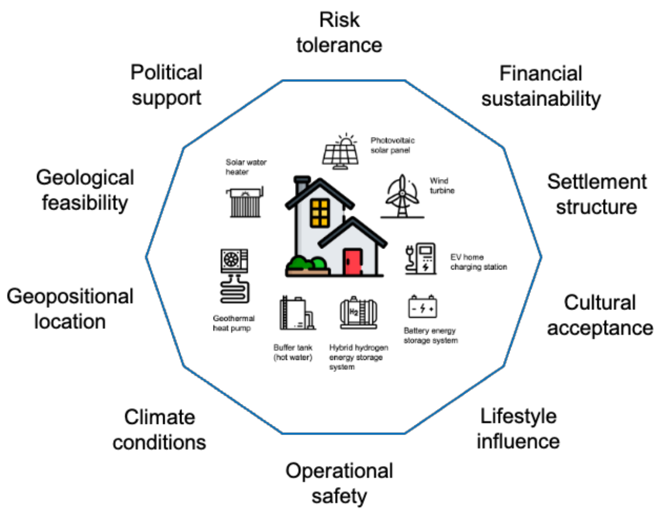


Figure 5 Environment defining the potential for individual households to function as DERs (own figure).
Source: icons from https://www.flaticon.com.

While local and cantonal programs subsidize solar heat and power systems, and heat pumps[37,38], the installation of equipment is regulated by various authorities (see sections below).

III. Analysis

A. Decentralized energy production and storage options in Zurich

1. Solar energy

Geographical conditions to produce energy from solar radiation in Zurich

The efficiency of solar energy production depends on the geographical location, as well as climate and weather effects on solar radiation. The potential for solar energy production of both, solar heat and photovoltaics, depends on the solar radiation reaching the earth surface.[39] Annual maps of solar irradiation at the surface and sunshine durations are depending on the geographical location. In Switzerland, the mountain regions and the southern parts of the country receive more solar radiation over the course of a year than the area around Zurich (Figure 6 and Figure 7).[40]

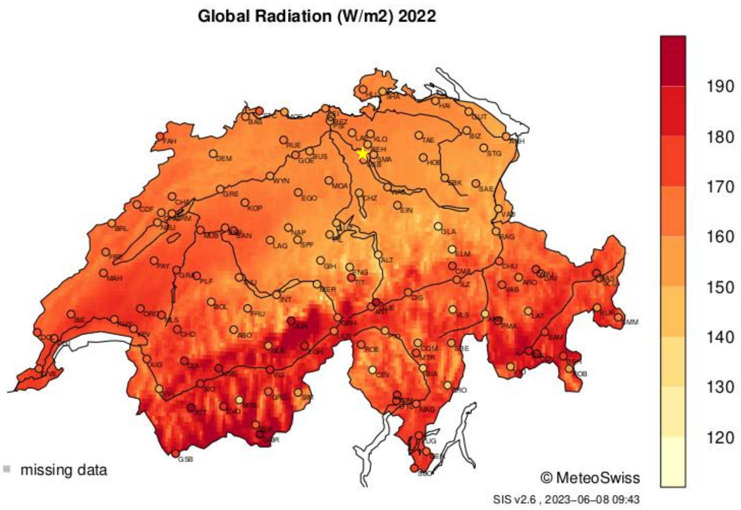


Figure 6 Solar radiation in W/m² at the surface across Switzerland in 2022. The location SMA (top center to the right) represents SwissMeteo in Zurich Fluntern (location of Zurich indicated by asterisk). Source SwissMeteo www.meteoswiss.admin.ch[40].

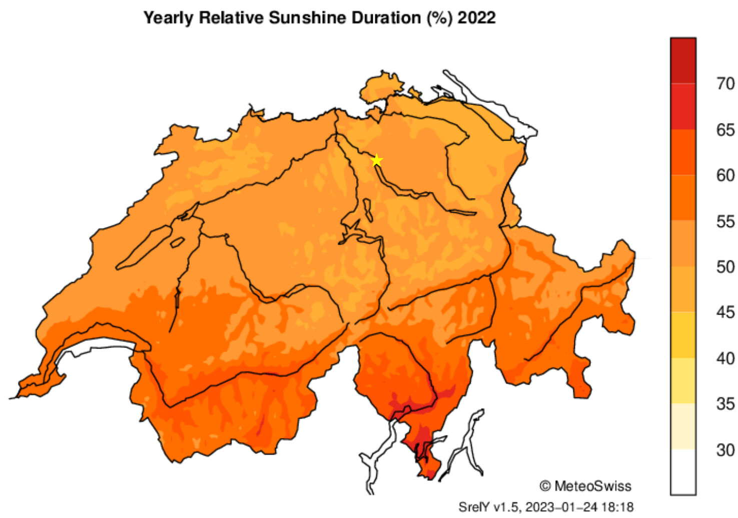


Figure 7 Average sunshine duration in 2022 across Switzerland. The relative duration of sunshine given in percent describes the ratio of registered hours of sunshine relative to the absolute possible duration of sunshine from sunrise to sunset at a location *(location of Zurich indicated by asterisk).* Source SwissMeteo www.meteoswiss.admin.ch[40].

The efficiency of solar energy production also depends on the orientation of the solar collectors and photovoltaic panels (Figure 8). Increasing technical efficiency renders also formerly non-optimal orientations usable, broadening the application potential as illustrated for the city of Zurich (Figure 9).

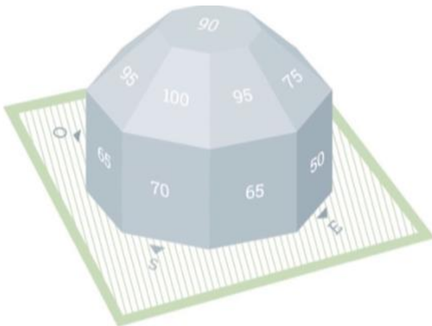


Figure 8 Orientation and yield of solar power systems: Annual solar irradiation on differently oriented roof and facade surfaces. The maximum is reached with south orientation and 30° inclination.
Source and figure: Swissolar www.swissolar.ch [26].

Solar heat

Solar heat collectors are easy to install, and sufficient roof area is available in Zurich. They are visually non-disturbing and do not generate any immissions. With increasing energy efficiency of buildings in the future, solar water heaters could cover more than 50% of the energy related to warm water and more than 20% for heating, respectively in newer buildings.

Photovoltaic systems

Photovoltaic systems are the primary solution for decentralized electricity production. The roof area required to produce higher amounts of electricity is however rather large. While the required space is available on single family homes or small apartment buildings, large apartment buildings may not dispose of sufficient south-oriented roof space for all parties (Figure 9). Installations with up to 30 kWp capacity are likely the maximum achievable for average residential buildings.

Solar energy						
Rooftop suitability	not determined	low	intermediate	good	very good	excellent

Figure 9 Suitability zones for solar energy in Zurich (partial area shown).
Source GIS Zurich www.maps.zh.ch[41].

According to studies for the city of Zurich[42], 3.01 km^2 of roof space in the city could produce 487 GWh of electricity in the future, confirming the here assumed output of 5 kWh per year per m^2 of installed PV. In addition, 80 GWh from building facade installations plus an undefined rather large contribution could come from other surfaces. Whether in the future building regulations will allow also free-standing solar panels at a larger scale will define what total output can be achieved per household.

2. Heat exchange energy

Geographical conditions for energy production by heat exchange systems in Zurich

The local geographic conditions for energy production via heat exchange systems are rather favorable in Zurich. The average annual temperature ranges around 10°C with temperatures rising rather rarely above 30°C in summer or falling below -10°C in winter, respectively (Figure 10).

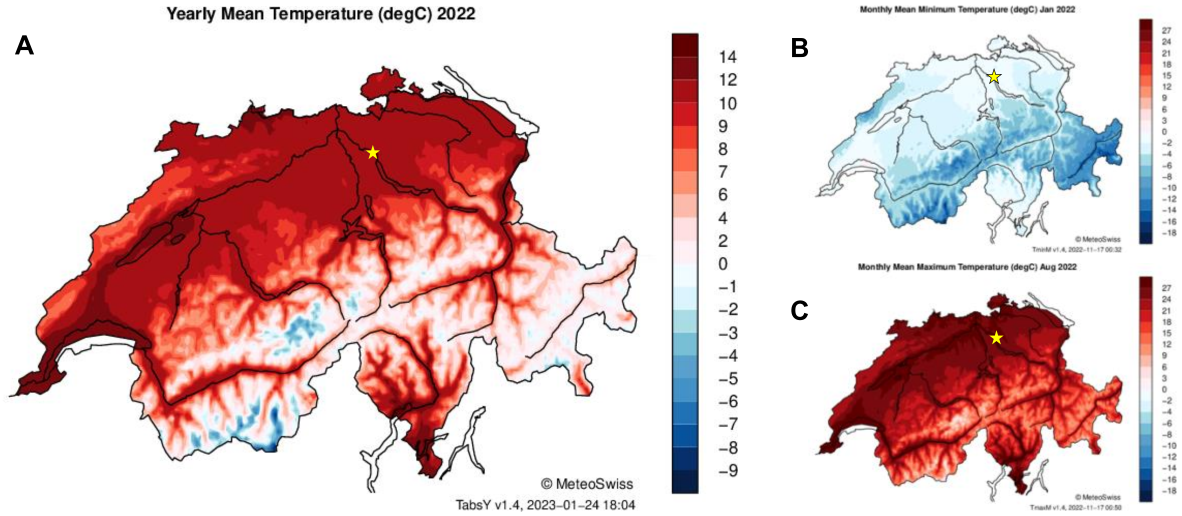


*Figure 10 **A** Annual mean temperatures in Switzerland 2022 in °C, **B** January 2022, **C** August 2022 (location of Zurich indicated by asterisk).*

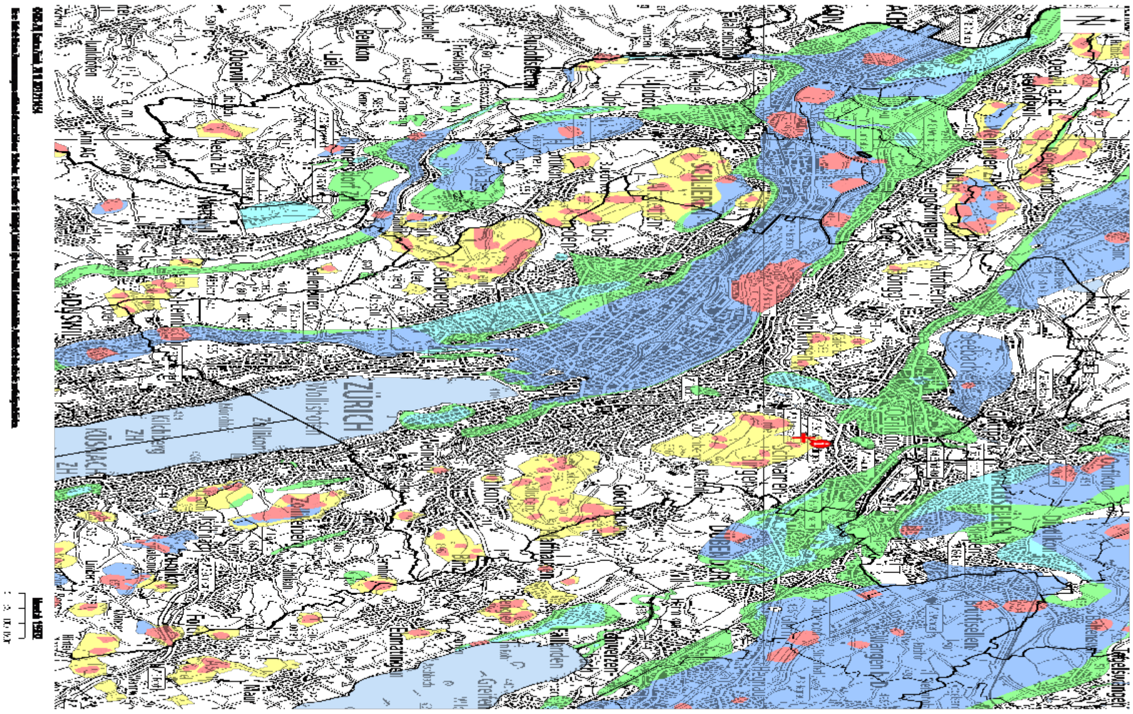
Source and figures SwissMeteo www.meteoswiss.admin.ch[40].

Air-Source Heat Pumps

The local geographic conditions for ASHPs are rather ideal in Zurich. Neither are very cold temperatures in winter very common nor rise temperatures in summer too high, as shown in Figure 10. Under these conditions, ASHPs work well for both, heating, and cooling of buildings.

Geothermal Heat Pumps

Heat pumps are very well suited to provide efficient heating energy. While ASHPs can be economical for individual household sizes considered here, GSHPs are best suited for higher energy demands. While being a disadvantage for complete flexibility at the household level, their efficiency and limited surface space requirement render them ideal for heating also larger buildings. For reasons of efficiency, heat pumps are ideally combined with large surface heating installations in the apartments, like floor or wall heating. For GSHPs, the city of Zurich is partially suitable, limited by restrictions for drilling deep geothermal probes in drinking water protection zones. The suitable zones encompass approx. 75% of the inhabited areas (Figure 11), which is also reflected by the existing GSHPs with geothermal probes (Figure 12).



Zone	A	B	C	D	E	F
Ground water situation	ground water, suitable for drinking water	ground water, suitable for drinking water	ground water, not suitable for drinking water	ground water, not suitable for drinking water	source water, suitable for drinking water	outside of usable ground water
Geothermal probes	prohibited	prohibited	allowed, special requirements	allowed	allowed, special requirements	allowed

Figure 11 Suitability zones for geothermal heat pumps in the city of Zurich. Data from GIS Zurich.
Source GIS Zurich www.maps.zh.ch[43].

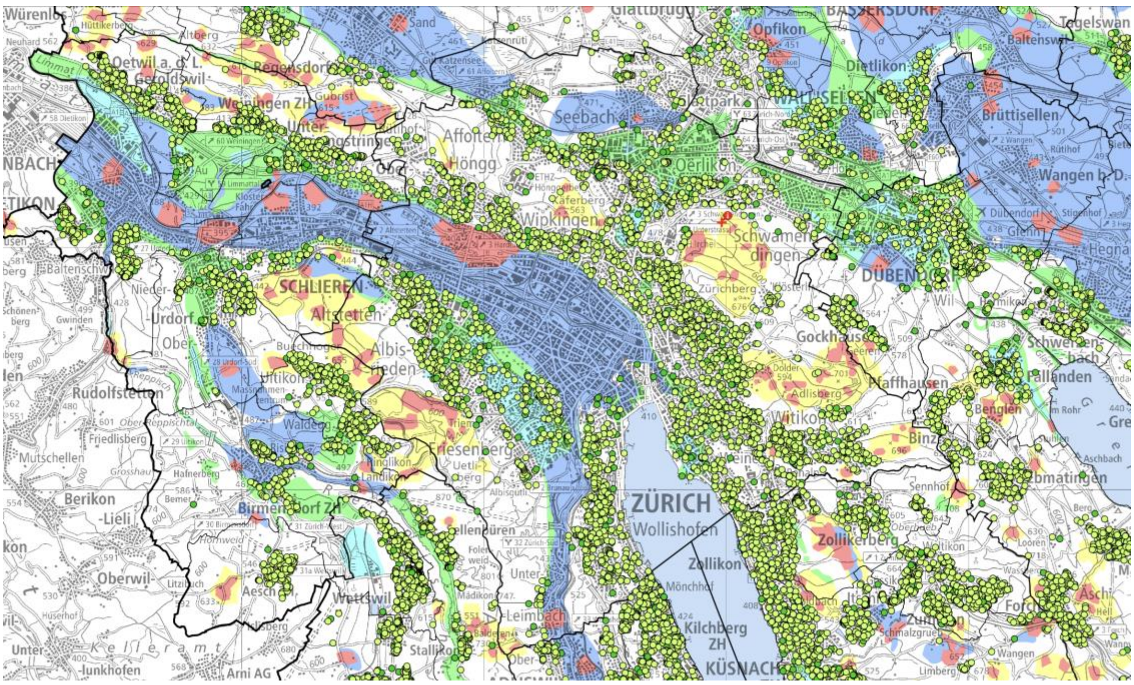


Figure 12 Geothermal installations with drilling profile ● and without drilling profile ○. Data from GIS Zurich.
Source GIS Zurich www.maps.zh.ch[43].

3. Wind energy

Geographical conditions for wind energy production.

Wind turbines provide an ideal supplement to photovoltaics. According to the 2050 energy perspectives, wind energy could account for around 7 to 10 % of Switzerland's electricity consumption in the future.[44] The cantons are responsible for planning the locations of wind power plants as they specify where these may be constructed and where they may not.

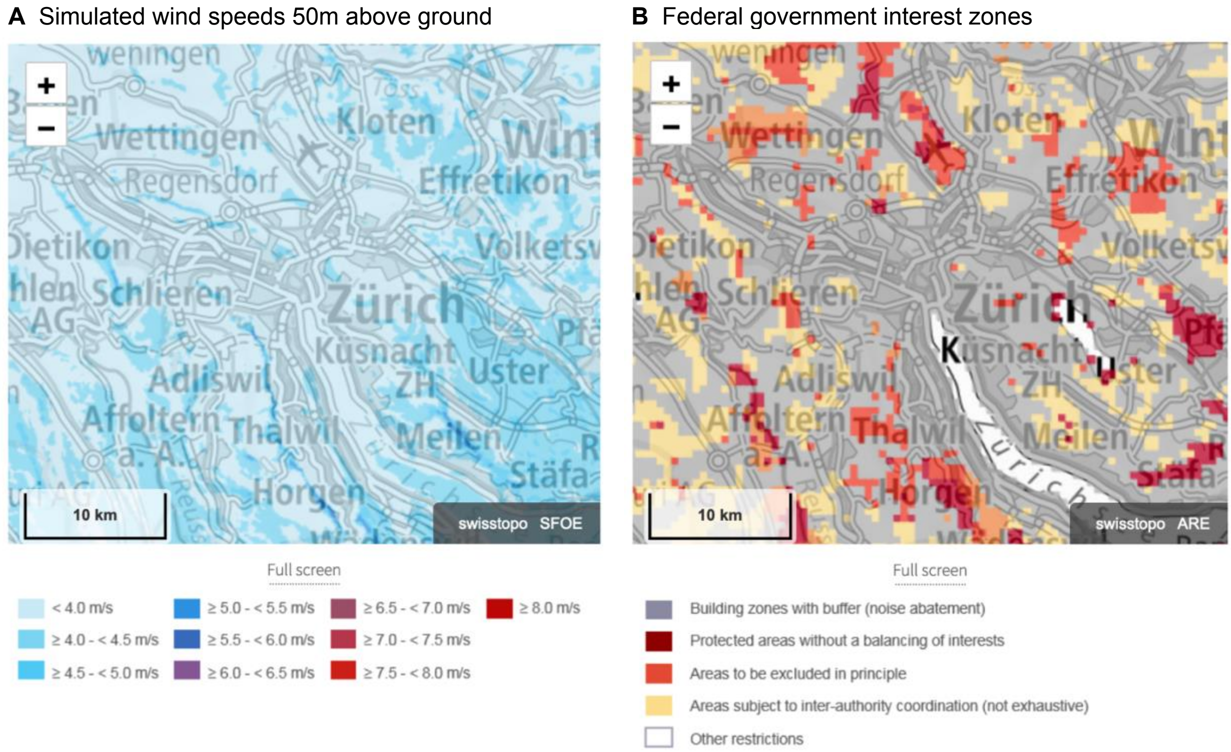


Figure 13 ***A*** *Simulated wind speeds in Zurich,* ***B*** *Interest zones leading to restrictions for wind power plants.* Source Federal Office of Energy www.uvek-gis.admin.ch [45].

Their planning must consider exclusion and restriction zones. In addition to regulatory considerations, wind energy, more than solar and much more than heat pumps, depends on the suitability of the location.[45] The respective data for simulated average wind speeds and for regulatory restrictions for the Zurich metropolitan area are shown in Figure 13, showing that the required minimal wind speeds of more than 4 m/s are not reached in Zurich.

As wind turbines need to be high off the ground and generate noise, permits within city limits will be granted only very restrictively. In addition to noise, other restrictive factors need to be considered, leading to large parts of settlement areas not only being not suitable for wind speed and consistency reasons, but also for regulatory reasons (Figure 13 B). To address all factors combined, for commercial wind energy installations, the Canton of Zurich has produced a suitability map (Figure 14).[46] With the exception of area 41 (Buechhoger, to the west of the city), none of the suitable areas for commercial systems overlap with Zurich city areas.

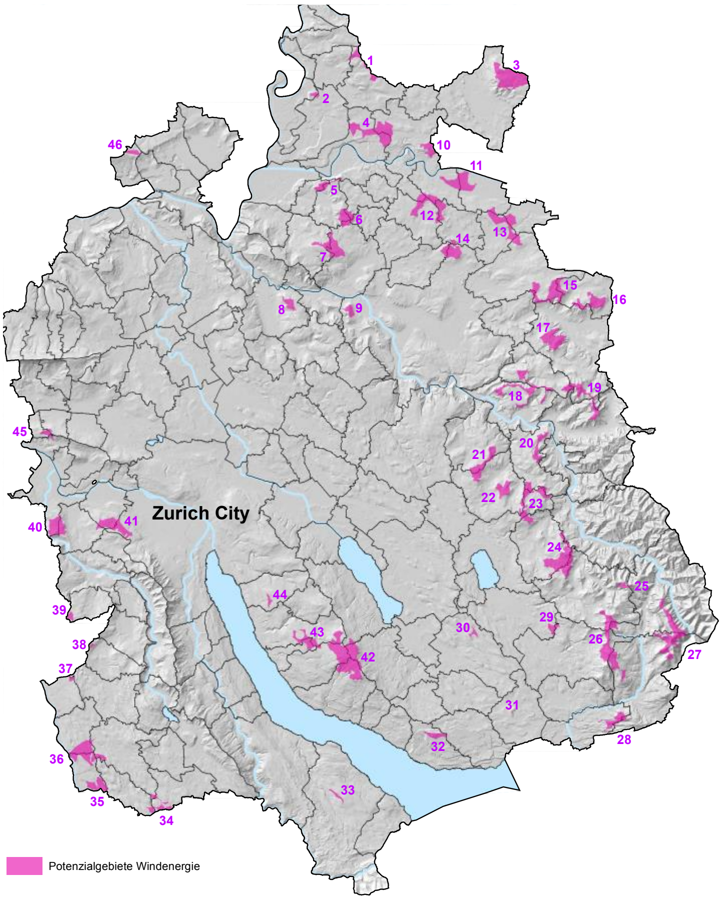


Figure 14 Areas with significant potential for wind energy (pink areas) in the canton of Zurich
Source Kanton Zürich Baudirektion. Potentialgebiete Windenergie 2022[46].

Wind energy within city limits of Zurich has very limited potential due to the geographic situation of the city between different hillsides (Uetliberg, Zürichberg, Käferberg) and regulatory limitations in densely populated areas. If future regulations permit, a lower end average output of 2'500 kWh per year for small private wind power plants could be considered, but must be excluded from the calculations here, as it is unrealistic for households in apartment houses to install the required number and size of wind turbines in the near future.

4. Energy storage systems

Short-term energy storage in batteries or longer-term storage in hybrid hydrogen storage systems are feasible and are not expected to face regulatory hurdles in Zurich. While still rather expensive today, a significant reduction in cost per kWh is expected to render the technologies broadly usable within a few years. For the present study, a storage capacity of at least 20 kWh from a combination of buffer tanks, buffer battery, and BEV battery systems is considered achievable, with future hybrid hydrogen systems expanding this capacity considerably.

B. Comparison of energy consumption and decentralized energy production

1. Comparison of energy demand and decentralized production

Covering heating needs

The energy demand for heating purposes, including warm water and room heating, has been determined to be 4'800 kWh for the average household in Zurich. There is a strong dependency of the energy need on the quality of the building. Based on the researched technical performance numbers, the setup in Table 10 would be needed. For an average household living in a single family home, slightly higher amounts would need to be covered. Using a GSHP instead of an ASHP, this would easily be possible, even though investment costs would increase.

Table 10 Covering heating needs of an average apartment building household in Zurich, (own calculations).

System	Energy (kWh p.a.)	% Energy Covered	Dimension	Investment Cost
Solar Heat	2'200 kWh[1)]	50 % warm water 20 % of heating	5 m^2 roof area	15'000 CHF
Heat Pump ASHP[2)]	5'000 kWh[2)]	up to 80%, depending on building efficiency	1 m^2 outside ground area	6'000 CHF
Buffer Tank	25 kWh (storage only)	short- to mid-term storage	500 l volume	15'000 CHF
Warm Water & Heating	4'776 kWh[3)]	total need, average building quality	79 m^2 and 2.01 persons	
Net Heat Energy p.a.	**~ 2'000 kWh**	**net energy overproduction**		

[1)] provided sufficient buffer storage bridges between summer production and winter usage, 20% of total need is assumed to be produced. Production of 2'200 kWh per year under optimal operational conditions (exposure, orientation). 200 kWh of electricity are needed to run the heat collector pump.
[2)] ASHP considered here, as for apartment buildings it would be difficult to install multiple independent GSHPs. Assumed 5'000 kWh production per year while 1'400 kWh electricity consumed.
[3)] Calculation of average need - see Table 7.

As shown, the energy needs for heating and warm water of an average Zurich household can technically be covered with reasonable investments and current technologies. Over the course of a year, approximately 2'000 kWh of heating energy could be produced above the direct need. This energy could be used to offer redundancy or, during times of reduced need, to save electricity of the heat pump by relying more on solar heat.

Covering electricity needs

The demand for electricity has been determined to be 2'200 kWh for the average Zurich household in apartment buildings and 3'500 kWh in a single family home, both for the respective average household size. To account for the additional electricity to run a heat pump, 1'400 kWh are added. The electricity to operate the solar heat collector is assumed to be 200 kWh per year.

Table 11 Covering electricity needs of an average Zurich apartment building household, (own calculations).

System	Energy (kWh p.a.)	% Energy Covered	Dimension	Investment Cost
Photovoltaics	5'000 kWh[1)]	assumed ideal conditions	30 m^2	10'000 CHF
Wind turbine[1)]	NA	NA	-	-
Battery Storage	5 kWh (storage only)	short- to mid-term storage	(alternative use of BEV with 80-100 kWh capacity)	3'000 CHF
General Electricity	2'200 kWh[2)]	household electricity (general/appliances)		
Air-Source Heat Pump	1'400 kWh	electricity to run pump		
Solar Heat Pump	200 kWh	electricity to run pump		
Net Electrical Energy p.a.	**~ 1'200 kWh**	**net energy overproduction**		

[1)] currently not realistic in respect to building permission, also not ideal geographical position in Zurich.
[2)] Calculation of average need - see Table 6.

As shown, the electricity needs of an average Zurich household can technically be covered with reasonable investments and current technologies. Over the course of a year, approximately 1'200 kWh of electric energy could be produced above the direct need of an average household in an apartment building. For an average household of two persons in a single family home, the overall electricity need would be met without an excess of produced electricity.
In case of a surplus in electrical energy, this could be fed back into the public electricity grid, or, even more economically, be used for covering other own energy needs. This could include the charging of a battery electric vehicle. For charging a BEV with an annual traveling distance of 10'000 km, electricity produced by photovoltaics would need to amount to approximately 1'300 kWh, which corresponds largely to the excess amount calculated here. If additional photovoltaic capacity would need to be planned, as in the above scenario for a single family home, a system with about 1.7 kWp or 10 m^2 of suitable roof area would be sufficient. The added benefit of a BEV could also be that the vehicle, if disposing of vehicle-to-grid capability, works as a big battery and increases the efficiency of photovoltaics as it can buffer the produced electricity (provided the vehicle is not used when buffering capacity would be needed). As cars within the city are often not used for commuting, BEVs could be available to function as battery buffer storages for self-produced electricity during these times.

2. Average coverage versus time-critical coverage of energy needs

The above analysis shows that the overall energy needs of an average household in Zurich can be met by autonomously generated heat and electricity. When considering the practical implementation, additional factors need to be considered. Due to the geographical location of Zurich, seasonal differences in the amount of solar radiation directly affect the practicality of DERs. While heating energy is primarily needed between October and April, in these months the least solar energy is available for use by solar heat systems. In parallel, for the generation of electricity by photovoltaics, also necessary for powering heat pumps, is equally at a minimum. In contrast, when the least heating energy is needed, the most solar energy is available (Figure 15).

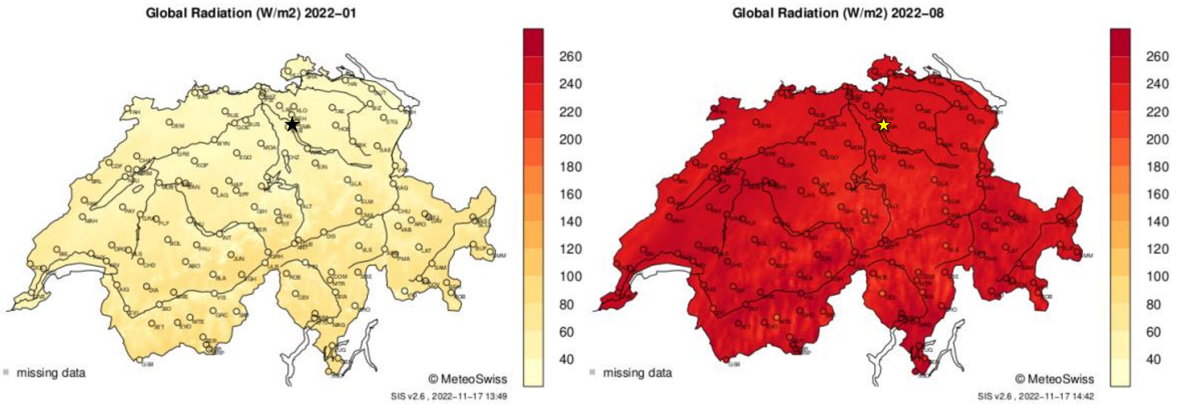


Figure 15 Solar radiation in Switzerland 2022 for the month of January (left panel), solar radiation for the month of August (right panel), (location of Zurich indicated by asterisk).
Source MeteoSwiss www.meteoswiss.admin.ch[40].

In terms of demand, the monthly needs for heating can be estimated to approximately 700 kWh for January/December, 500 kWh for February/November, 300 kWh for March, 200 kWh for April/October, 100 kWh for May, 0 kWh for June to September. For warm water, the energy needed year-round amounts to approx. 70 kWh per month. For household electricity an average of 150-200 kWh per month can be assumed, with 150 kWh during the summer months and 200 kWh during winter.[47]

Based on these figures, the resulting monthly household energy demand ranges from around 1'000 kWh in January to roughly 200 kWh in August. By generating heat via solar collectors and heat pumps, the respective demand is decreased to the operation of the pumps, for which one can assume a coefficient of performance of 4, resulting in roughly 400 kWh and 200 kWh of electricity needed for January and August, respectively. During November through February, the solar heat collectors can be expected to cover around 30% of the warm water or less than 10 % of warm water plus heating demand, leaving the bulk of heat generation to the heat pump. The photovoltaic system can be expected to produce around 200 kWh per month during winter and around 600 kWh during the summer months (Figure 16).

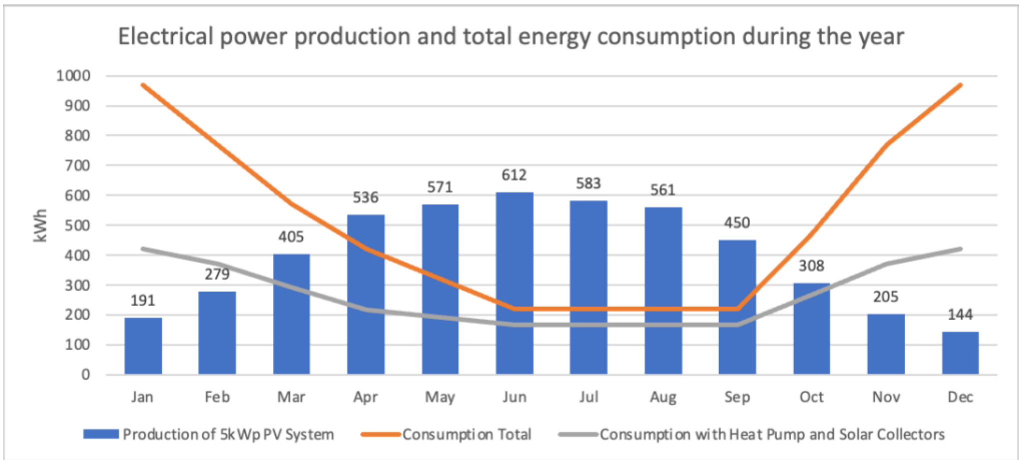


Figure 16 Monthly electricity production in kWh by a 5kWp photovoltaic system at the location of Zurich (own graph).

Source Swiss Federal Office of Energy www.energieschweiz.ch[47].

Like the monthly fluctuations discussed above, Figure 17 shows the daily fluctuation of temperature and sunshine duration in Zurich for the year 2022. Due to the short-term nature of these fluctuations, the amount of under-produced energy for heat generation and appliance powering can be compensated by the existing hot water and battery storages.

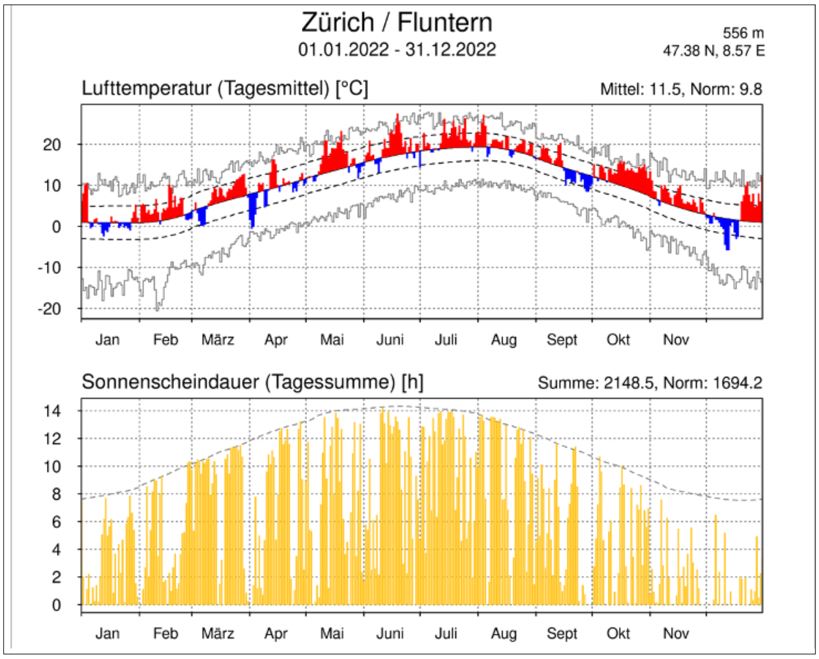


Figure 17 Fluctuation of air temperature and daily sunshine duration in Zurich in the year 2022.

Source MeteoSwiss. www.meteoschweiz.admin.ch[48].

3. Overall feasibility analysis

As becomes evident from the calculations above, the photovoltaic and solar heat systems lead to an underproduction compared to the energy need from November to February, when considering the electricity needed to run the heat pump and the solar collector pump, while also providing general household electricity. On the other hand, from March to October, the production is likely exceeding the direct needs, so that electricity during this time could be used to charge a BEV and hence reduce the overall energy consumption by partially meeting mobility demands.

There are multiple solutions to address the identified temporal imbalance between energy need and energy production.

- One solution would be to triple the photovoltaic system to 15 kWp, which would deliver more than 400 kWh per month also in December, the lowest efficiency month. As this would correspond to around 80 m^2 of solar panels, it must be considered impractical (and costly) with current technologies.
- Alternatively, longer-term energy storage solutions could bridge between the over-productive and under-productive months. These systems would need to be able to store the excess energy in the form of electricity or heat for at least 5 months (August/September until January/February). While this is technically not impossible, it would be highly uneconomically at present, even though the new chemical energy storage solutions currently under development could provide a solution for this.
- A third option would be to drastically reduce the need for heating energy. By following latest building standards for minimal energy buildings, the amount of heating energy can be reduced by as much as 80%.[18] While the photovoltaic system discussed here would not fully cover the other electricity needs, a much smaller increase in peak capacity of the system would then be sufficient to cover the demand.

4. Expert comments on the current state and future of decentralized energy production in Zurich

To complement the technical and geographical analysis, interviews with experts of the energy sector and for sustainable city development were carried out. A written interview was carried out with Hardy Schröder, Team Leader Energy Consulting of the Elektrizitätswerke des Kantons Zürich (EKZ). Personal interviews were carried out with Arjen Visser, Head of Tarif Management at Elektrizitätswerke der Stadt Zürich (EWZ) and with Silvia Banfi Frost, Energy Commissioner of the City of Zurich.

Interest in decentralized and autonomous energy generation among private consumers and areas that are currently in most demand

Expert feedback: There is considerable interest from private households in sustainable and renewable energy production. Where possible, households are increasingly installing photovoltaic systems to produce electricity and heat pumps for the generation of heating energy.

Relative importance of financial, ecological, or political/strategic considerations

Expert feedback: End consumers, in the city of Zurich mostly households in rental flats, are primarily motivated by ecological motifs as they cannot chose the energy supplier or decide on their own whether they would want to produce electrical energy autonomously. The respective choice is limited to taking advantage of renewable energy offerings of the energy suppliers. The heating of their flat or building is outside of their area of influence. On the other hand, end consumers living in single family homes, or non-end consumers as in the case of real estate companies or organizations, are largely motivated by financial incentives or they react to regulatory pressure and laws. For public institutions, in the case of Zurich the City of Zurich itself as one of the major real estate holder, the ecological and political/strategic considerations are of paramount importance.

Assessment of the current development

Expert feedback: With the help of the energy suppliers EWZ and EKZ, the political institutions foster the installation of photovoltaic and heat exchange technologies. Measures include extensive consulting offerings plus financial incentives for the early replacement of heating systems based on fossil energies. The increasing awareness of the public for issues of climate change supports the efforts, but the limited technical options for many households affect the translation into concrete actions. Furthermore, environmental and monument protection laws are limiting the installation of widespread PV or heat exchange systems in certain geological or historical areas of the city. In parallel to sustainable and potentially decentralized energy production, energy conservation measures are of central importance. Particularly around heating energy, energy efficiency measures would greatly reduce the need for energy in the first place and render alternative solutions to fossil technologies realistic in terms of capacity. However, the lack of respective binding regulations is hampering progress.

Realistic goals for decentralized energy generation by private households in Zurich

Considering the limitations in what individual households as tenants in Zurich can technically implement themselves, a significant energy production of private households is considered not the primary goal. Technically, the installation of sufficient DER capacities would be possible in many cases, but boundary conditions from environmental or protection regulations make it currently non-sustainable. In those cases, centralized rather than decentralized sustainable technologies are implemented. Particularly district heat is favored by city development, as it can be produced largely from renewables and efficiently supply households that are otherwise limited in the installation of eco-friendly solutions. For private households in single family homes or smaller housing estates, an autonomous energy supply could technically be achieved, particularly if combined with energy efficiency measures applied to buildings. In all cases, fully autonomous energy supply is considered inefficient, as the coverage of peaks in demand, e.g. during winter, would require significant overcapacities during the rest of the year, making the respective installations financially unattractive and even technically difficult to install, given space and immissions constraints.

The role of politics

Expert feedback: Awareness and broad support for environmental topics has greatly increased in the public over the past years. Fueled in addition by a looming energy crisis and a war in Europe, people are paying much closer attention to energy related topics and start to make connections between global climate change, regional and global energy politics, and their own supply of electrical and heating energy. While education and incentives have led to an increase in the adoption rate of new technologies and decentralized energy production, financial incentives are still the main driver for a larger-scale shift towards renewable energy solutions. This is underlined by the major impact new community and cantonal laws have on the shift away from fossil fuels and the installation of PV and heat exchange systems. All experts agree on the positive effect of the respective regulations and consider further steps, particularly concerning measures for energy conservation and increased efficiency, as key elements for the continued transition.

Further development over the coming years

Expert feedback: The continued development of energy generation technologies, but very prominently also energy storage technologies, are expected to increase the level of possible energy autonomy at the regional but also local level. In the case of individual households, further progress will be necessary at the energy generation and energy efficiency levels, to also enable households in non-single family homes to become potentially autonomous, what is already possible for new single family homes today. In line with the political will to achieve a net-zero CO_2 balance in Zurich, additional regulations and laws would be required or even essential to generate the boundary conditions for financially and ecologically sustainable solutions.

IV. Discussion and Conclusion

1. Answering of the research hypothesis

Based on the research question on ***the technical options and chances of feasibility regarding the democratization of energy production and a future autonomous supply of individual households in Zurich, Switzerland,*** it can be concluded:

The overall energy production of an average Zurich household, equipped with current solar heat collectors, air-source heat pump, photovoltaics, hot water tank, and electrical battery would be technically sufficient to cover the total annual need of electrical and heat energy of the respective household. This is true for single family homes or small residential buildings, whereas for larger residential buildings and tenant households, the respective space constraints make achieving the required installation capacity technically challenging.
Unlike the view on the total energy need and production capacity over the course of a year, the analysis of season-specific capacities provides a more differentiated result. Due to the geographic location of Zurich and the resulting need for heating energy during the months with the least solar irradiation, a photovoltaic system of realistic dimensions for an inner-city location would not be able to generate sufficient time-critical electricity to power household and heat generation devices. This true for tenant households, as well as for single family homes or small residential buildings that have not been built to recent high energy efficiency standards. As wind turbines are not a realistic alternative due to the geographical location and population density, the gap in electrical energy in winter months can currently not be closed. The alternative option, to bridge the time between energy production in summer and energy consumption in winter, using any form of battery technology, is not realistic with technologies that are available to households today and likely not in the very near future.

As a conclusion and based on the data collected and analyzed, the research hypothesis that a democratization of the energy production and a future of autonomous energy supply of an individual household in Zurich, Switzerland can be achieved, must be rejected when looking at the near-term future.

Even though the assumed feasibility could not be demonstrated under present and near-future conditions for average households in a densely populated city, the situation might change over the coming years. Given the latest progress in the development of small-scale chemical energy storage systems, options to convert electricity in long-term storable hydrogen and the re-conversion using fuel cells, the improvements in building quality and thermal isolation efforts in older buildings, and not last the constantly increasing efficiency of photovoltaic panels, make it technically very possible that truly energy autonomous households are achievable in Zurich within the coming decades. This has been confirmed by the interviews carried out with experts from the local energy suppliers and the Office for Urban Development of the City of Zurich. Whether such solutions will finally be implemented in a widespread manner, will depend on the boundary conditions defined by politics, as well as the availability of potentially more economical centralized and semi-centralized renewable technologies, including larger-scale photovoltaic installations and district heat systems.

2. Limitations and implications of the study

While the future is likely not following a scenario that consists of exclusively decentralized and DER-based energy production, they will undoubtedly play a prominent role. Potential limitations of the research study due to various factors, are summarized in different categories below.

Limitations of information resources and precision of calculations

Various information resources for energy demand and production capacity calculations were originally made for single family homes with four persons. For the present work, these numbers were proportionally corrected to reflect the average household size in Zurich. Where relevant, a distinction was made between average households living in single family homes and those living in apartment buildings. For a more precise calculation of needs and the feasibility of autonomous energy supply, the individual numbers would have to be precisely calculated. The same holds true for the plethora of technical solutions for energy generation and storage. The present work could only evaluate a selection of the many technical options, which in practice would also depend on the individual conditions of the household in question.

Influence of geographical conditions

The conditions, which define what amount of power can be produced locally by what technology, are primarily influenced by the geographical location of the installation. As the city of Zurich offers very heterogeneous conditions in respect to the possible orientation of solar panels due to hillsides or forests, or the option to use geothermal heat pumps due to protected ground water, an "average" location for a single family home or apartment building in Zurich does not exist. Within the large range of conditions, some would perfectly qualify for decentralized energy production, while others are basically unusable.

Economic factors

For the evaluation of feasibility of DERs and autonomous energy supply, the study focused on technical arguments. Whether DERs will finally become more relevant will also depend significantly on their economic attractiveness. The presented work addresses broadly estimated investment costs for the required components, which suggest that in relation to building costs and rent costs/income in Zurich those costs would be reasonable. However, no precise economic sustainability calculation has been carried out, as such would only be possible after defining the exact conditions and technical options at the precise location of the individual household of interest. Potential subsidies by the local government and state-owned energy providers obviously are and will remain relevant for the respective calculations.

Urban development regulations and restrictions

Rules and regulations for urban development are currently hindering a more widespread implementation of DERs in particular locations within the city of Zurich. While geographical and technical limitations are clearly the most limiting factors that define whether DERs are locally feasible or economically sustainable, urban development rules can interfere at locations, where decentralized energy production would in principle be technically feasible and well worth economically and ecologically. As long as landscape protection rules, although mostly relevant outside of cities, and monument protection laws or aesthetic guidelines for urban development, mostly relevant in urban areas, are trumping the benefits of DERs, their development in city areas will be limited. Politics and the public will at one point have to decide, whether a sustainable energy generation that ensures the working of a modern society and economy, will be valued higher.

Local cultural aspects and acceptance

Closely connected to the arguments concerning urban development and landscape protection, the public, particularly in Switzerland and Zurich, will have a prominent influence on the implementation of DERs in Zurich. To enable the transition to decentralized and sustainable local energy production, large installations of solar heat and photovoltaic panels would be required on all suitable buildings in the city. In addition, storage tanks for heat and chemically converted electricity would need to be built. Where possible, also wind turbines should be installed, even if those will not be completely immissions (noise) free.

Incentives for autonomous energy production

Constant increases in the efficiency of the technologies are expected to be realized over the coming years and decades, with the possibility of improvements by factors or even orders of magnitudes. This would render the goals of the energy production close to trivial. In parallel, the increase in technical efficiency is likely to be accompanied by a decrease in cost per generated or stored kWh of energy. With this, the affordability of the equipment and amortization of investments would greatly be improved. While current systems require decades to pay for themselves in terms of savings compared to purchased energy, the new systems would likely produce a net income within only a few years and hence create significant incentives for investing in household DERs.

Global perspective and political motivation

Climate change is leading to increasing temperatures and more extreme weather, resulting in significant shifts of the global economy. It also influences the habitability of whole geographic regions, and much more. It is therefore of utmost importance that the production of CO_2 is sustainably reduced, which is most easily achieved by saving energy but also by the local and CO_2-free generation of energy using solar power and heat pumps. Apart from the fact that these systems can not only be used to generate heating energy, but they can also be used to cool buildings and hence further reduce the need for electricity or indirectly fuels. It can therefore be expected that DERs will be increasingly supported by politics and the general public.

Implications of energy democratization beyond the individual level

Democratization also enhances energy security by reducing dependency on centralized energy production and imports. With this, the political influence of large energy production companies could be limited and more democratic interests, for the benefit of everyone, should become the focus of local and national politics. A reduced dependency on energy imports would not only be ecologically favorable, but also have an influence on foreign policy, which is currently often driven by (energy) economic interests rather than ethical values or ecological and economical sustainability. At the technical level, decentralized energy systems will also be more resilient to disruptions and can help to stabilize the power grids in cases of energy shortages.

3. Potential follow-up work

The present study has addressed the research question at a general level, based on an average scenario for the city of Zurich and under current political conditions. A deeper analysis will be required to clarify the final relevance and feasibility for the case of specific individual households. While the present study focuses on technical aspects, an in-depth financial analysis would need to be combined with a more comprehensive analysis of subsidies and incentives provided by the public sector. More work would also be required to include the viewpoint of the general public, as the acceptance and even implementation of new regulations and laws will depend on the acceptance by the voting population.

4. Personal reflection

Having always been interested in the protection of the environment and in topics of equality and democracy, the question whether both could be combined in a research topic immediately appealed to me. Changing our current energy supply from largely non-renewable fossil fuels that are major contributors to global climate change, to renewable and sustainable solutions is a huge task. While not all CO_2-producing energy sources can be replaced immediately and additional efforts at the personal and political level will be needed, fossil fuels to produce electricity and heating energy can be replaced today already in many areas. Combining this with the vision that every individual or household can generate their own energy, hence becoming independent from major corporations and potential political instability, for me is very positive and highly motivating.

5. Acknowledgement

I would like to express my greatest gratitude to my supervisor Claire Kick-Kerstens, who made it possible for me to write this research paper, by giving me feedback and helping me with any questions.
My deepest appreciation I would also like to express to Silvia Banfi Frost (Energy Commissioner of the City of Zurich), Arjen Visser (Head of Tarif Management at EWZ), and Hardy Schröder (Team Leader Energy Consulting EKZ), for taking the time to answer my interview questions in detail and providing expert input that enabled me to complement my work.

V. Appendix

A. Expert Interviews

The interviews were carried out in German. The sections below refer to the information provided to the experts in advance of the interviews (in person) and as a basis for the written responses (written interview).

1. Interviews with energy experts of the energy suppliers

Introduction provided to the experts

Background to the topic of the Matura thesis: Democratization of energy production and a possible future of autonomous supply for households in Switzerland: What are the technical possibilities and chances of feasibility regarding the democratization of energy production and a future autonomous supply for private households in Zurich?
The focus of the work lies in the current climate debate on achieving CO_2 targets, the discussion about dependence on fossil fuels and their political consequences, possible electricity shortages, the switch to electromobility and a variety of other aspects. While it is not possible to shed light on all aspects comprehensively, the current opportunities and possible future scenarios will be examined for at least one relevant sub-area, the supply of private households with heating energy and household electricity.

Interview questions

- Do you currently see a growing interest in decentralized and autonomous energy generation among private consumers?
- Which areas are currently most in demand?
- Are financial, ecological, or political/strategic considerations at the forefront?
- In your expert opinion, how should this development be assessed (irrespective of demand)? Should the aim be to increase energy generation by private households (assuming average residential and single-family households)?
- If yes,
  - which aspect should be in the foreground?
  - What degree of autonomy is technically feasible?
  - What level of autonomy should be aimed for and for what reasons?
- If not, for what reasons
  - economic / macroeconomic considerations?
  - technical limitations?
  - political limitations?
- What role does politics play in this (support measures, licensing regulations, etc.)?
- What changes do you expect in the next 10 years?

Written interview with Hardy Schröder, Team Leader Energy Consulting, Elektrizitätswerke des Kantons Zürich (EKZ). Zurich, December 12, 2023, (carried out in German, answers in black).

Sehen Sie zurzeit ein steigendes Interesse an dezentraler und autonomer Energiegewinnung bei Privatverbrauchern?

Die kann klar mit einem «JA» beantwortet werden. Vor allem die Nachfrage nach lokaler Nutzung der Sonnenenergie ist bei unseren Kunden weit vorne

Welche Bereiche werden aktuell am meisten nachgefragt?

Das Thema der Stromproduktion ist aktuell am stärksten gefragt. Dies zeigen auch die Zubaustatistiken von Swissolar[49].

Stehen dabei vor allem finanzielle, ökologische, oder politisch/strategische Überlegungen im Vordergrund?

In der Regel sind dies Ökologische Gründe aber auch strategische im Bereich der Versorgungssicherheit. An dritter Stelle wird auch der finanzielle Aspekt mit in Betracht gezogen.

Wie ist aus Ihrer Expertensicht diese Entwicklung zu beurteilen (unabhängig von der Nachfrage)? Ist eine verstärkte Energiegewinnung durch Privathaushalte anzustreben (Annahme durchschnittliche Wohnungs- und Einfamilienhaus-Haushalte)?

Wir stehen vor einer grundlegenden Umstellung unserer Energieversorgung: Zur Umsetzung des Pariser Klimaprotokolls ist es nötig, unsere Treibhausgasemissionen bis spätestens Mitte Jahrhundert auf Netto-Null zu senken. Solarenergie spielt dabei eine entscheidende Rolle. Das ausschöpfbare Gesamtpotenzial zur jährlichen Produktion von Solarstrom in der Schweiz liegt bei klar über 100 Terawattstunden, der grösste Teil auf Gebäuden. Hier gibt es auch Studien zum Solarpotential in der Schweiz[50]

Falls ja,

- welcher Aspekt sollte dabei im Vordergrund stehen?

Hier können die Interessen je nach Ansicht abweichen. So hat der Eigentümer eher ein Interesse an Selbstversorgung und Versorgungssicherheit, die auch günstig sein soll. Die Politik braucht aber für das Gesamtziel genügend Solarstrom um damit auch die nötigen saisonalen Reserven (Stauseen, Wasserstoff etc.) zu schaffen. Eine zu grosse Anlage kommt den Eigentümer aber eher teurer und lässt sich schlechter amortisieren

- welcher Autonomiegrad ist technisch realisierbar?

In den Gebäuden ist ein theoretischer Autonomiegrad/Autarkiegrad von 100% möglich. Es gibt dazu auch schon Projekte wie das Mehrfamilienhaus in Brütten[51]. Eine solche Lösung ist in der Regel aber sehr teuer und hat bis heute noch nicht viele Folgeprojekte mit sich gezogen.

- welcher Autonomiegrad sollte angestrebt werden und aus welchen Gründen?

Die Frage, welcher Autarkiegrad für Hausbesitzer realistisch ist, hängt von verschiedenen Faktoren ab. Eine vollständige Unabhängigkeit vom öffentlichen Energienetz, also ein 100%iger Autarkiegrad, ist momentan für die meisten Hausbesitzer nicht realisierbar, da die Speicherkapazität oft nicht ausreicht. Ein realistisches Ziel wäre jedoch ein Autarkiegrad von etwa 60–80 %. Man kann den Autarkiegrad allerdings erhöhen, indem der Überschuss an erzeugtem Strom in einem Batteriespeicher gespeichert wird. Jedoch sollte vorher genau berechnet werden, ob die Investitionskosten und der Wartungsaufwand in einem sinnvollen Verhältnis zum Nutzen stehen.

Welche Rolle spielt dabei die Politik (Fördermassnahmen, Bewilligungsvorschriften, etc.)?

Die Politik spielt dabei eine wichtige Rolle, so helfen vereinfachte Bewilligungspraxen eine Anlage umzusetzen und weniger Stolpersteine in den Weg zu legen. Sinnvolle Fördermassnahmen geben einen Anreiz eine Anlage umzusetzen, die ansonsten eine sehr lange Amortisationszeit hätte. Auch steuerliche Anreize können dabei helfen.

Welche Veränderungen erwarten Sie in den kommenden 10 Jahren?

Der Zubau von erneuerbaren Energien wird in den nächsten Jahren stark zunehmen. Dies nicht nur im Bereich der Solarenergie. Auch die Windkraft wird Ihren Teil dazu beitragen. Im Gegenzug wird durch die stetige Elektrifizierung der fossilen Systeme der Stromverbrauch zunehmen und die Stromnetze auf die neuen Gegebenheiten und Anforderungen angepasst werden

Personal interview with Arjen Visser, Head of Tarif Management at Elektrizitätswerke der Stadt Zürich (EWZ). Zurich, December 14, 2023, (carried out in German, answers in black).

Sehen Sie zurzeit ein steigendes Interesse an dezentraler und autonomer Energiegewinnung bei Privatverbrauchern?

Grundsätzlich sehen wir das, mit einem Fokus auf Solar(-Energie). Die Stadt Zürich beauftragt uns auf dem politischen Weg für mehr Solarenergie zu arbeiten. Auf der Seite der Konsumenten sehen wir auch, dass sich die Bürger dafür aussprechen - da sehen wir in der Stadt Zürich schon ein klares Interesse. Viele Privatverbraucher haben ausser der politischen Bekundung ja nicht viele Möglichkeiten etwas zu tun, da sie oft in Mietwohnungen wohnen. Auf der Verbraucherseite her kann in der Stadt Zürich bei den Stromprodukte wählen, wie ökologisch es sein soll. Es gibt zum Beispiel ein Solar Zürich Produkt, bei welchem man eine Fläche auf einem Dach für Solarproduktion mieten kann. Wir haben dafür viel Werbung gemacht und das Interesse ist sehr hoch. Man kann daran sehen, dass das Bewusstsein in der Stadt Zürich für erneuerbare Energien sicher da ist. Ob den Verbrauchern eine dezentrale und autonome Produktion wichtig ist, ist schwierig zu beurteilen.

Und bei den Firmen?

Die Firmen brauchen grundsätzlich so viel Strom, dass sie nicht komplett autonom sein können, daher geht es bei ihnen stärker um die Versorgungsicherheit. Damit stehen andere Themen im Vordergrund, aber auch Firmen beziehen immer mehr Erneuerbare (Energien).

Stehen dabei vor allem finanzielle, ökologische, oder politisch/strategische Überlegungen im Vordergrund?

Seit der (Strom-) Mangellage stehen oft auch ökonomische Aspekte im Vordergrund - wir hatten doch erhebliche Energieschwankungen bei den Grosskunden. Die meisten Kunden, da sie kleinere Verbraucher sind, können nur beschränkt wählen und bezüglich des Preises nehmen, was ihnen angeboten wird. Daher steht bei jenen der ökonomische Aspekt sicher nicht im Vordergrund: wenn man als Verbraucher eine Lösung für erneuerbare Energien nicht selbst umsetzen kann, stehen ökologische Interessen im Vordergrund. Als (Liegenschaften-) Besitzer sind es eher finanzielle, dann politisch-strategische und dann ökologische Überlegungen. Für jene muss also garantiert sein, dass sich eine Wärmepumpe oder photovoltaische Anlage amortisiert. Beim politisch-strategischen Argument kann die Aussenwirkung als umweltbewusst im Vordergrund stehen, bei den ökologischen Interessen sind es sicher persönliche Interessen.

Wie ist aus Ihrer Expertensicht die Entwicklung zu beurteilen, unabhängig von der aktuellen Nachfrage)? Ist eine verstärkte Energiegewinnung durch Privathaushalte anzustreben?

Als Stadt muss es ein Zusammenspiel sein. Wir werden in der Stadt selbst kaum die Möglichkeit haben, unseren (Energiebedarf) komplett zu decken, vor allem wenn der Verbrauch auf dem heutigen Niveau bleibt. Wir brauchen daher eine Kombination mit Grosskraftwerken in der Umgebung der Stadt. Da sprechen wir von grossen Wasser- und Windkraftwerken, bei denen man sich energietechnisch absichern kann. Wenn lokal produzierter Strom gleich vor Ort verbraucht wird, ist das natürlich ein grosser Vorteil, da man dann auch weniger Infrastruktur bauen muss und man die Infrastruktur ja auch wieder über den Strompreis verrechnen und bezahlen muss.

Glauben Sie, dass es früher oder später möglich und erwünscht sein wird, mithilfe gewisser Optimierungen und Effizienzsteigerungen, dass Privathaushalte sich selbst versorgen? Und dass man dann nur noch für Firmen und Grossproduzenten Energie extern produzieren würde?

Ich gehe nicht davon aus. Bei uns ist ein Kunde (primär) eine Wohnung in einem Haus. Ich denke im städtischen Gebiet ist das eher unrealistisch, weil die Energiedichte viel zu gross ist, wir brauchen viel Energie pro Fläche. In Einfamilienquartieren oder in ländlichen Regionen kann das anders aussehen. Durch energieeffizientes Bauen und entsprechender Energieproduktion vor Ort, könnte man möglicherweise tatsächlich Autarkie erreichen und man gar keinen Netzanschluss mehr benötigt. Oder zumindest nur noch für ausserordentliche Notzustände oder Extremereignisse.

Welche Rolle spielt dabei die Politik (Fördermassnahmen, Bewilligungsvorschriften, etc.)? Es gibt ja zum Beispiel das neue Klimagesetz des Kantons und das hat den Ausbau der Photovoltaik massiv gefördert.

Die Politik spielt eine sehr grosse Rolle. Man versucht schon länger, über Anreize wie verstärkte Förderung, das (die Wende zu erneuerbaren Energien) zu regeln. Es braucht daneben aber ganz klar auch zwingende Vorschriften, da es ohne diese nicht wirklich funktioniert. Wir sehen das auch klar an der Wirkung der jetzt vorhandenen Vorschriften.

Welche Veränderungen erwarten Sie in den kommenden 10 Jahren?

Es kommen jetzt verschiedene Sachen. Aus dem «Mantelerlass», ein neues Energie- und Stromgesetz auf nationaler Ebene, worüber vermutlich im frühen Sommer abgestimmt wird, würden per Ende Jahr verschiedene neue Massnahmen realisiert. In deren Rahmen würde explizit lokale Energiegemeinschaften möglich.

Wieso glauben Sie, dass der Anbau von erneuerbaren Energien und diese dadurch fortschreitende Autonomisierung nur mit einem Gesetz wirklich funktioniert und nicht mit den ganzen Anreizen?

Auch als persönliche Ansicht, denke ich, dass es damit zu tun hat, dass Vermieter oder Immobilienfirmen die Kosten auf die Kunden überwälzen. Ein Vermieter hat nur ein Interesse, zu investieren, wenn man die Kosten weiterbelasten kann. Bei einer Photovoltaik-Anlage ist es so, dass er diese nicht auf die Mieter überwälzen darf. Bei der Heizung sieht das anders auch. Entsprechend ist die Motivation zur Veränderung und Investition gering und es braucht entsprechende Möglichkeiten, Investitionen attraktiver zu machen oder über Vorschriften zu erzwingen. Hierzu gibt es schon erste Modelle und die Anreize nehmen zu, womit sich diese Anlagen auch amortisieren lassen. Aber leider ist das noch nicht bei allen Planern und Immobilienfirmen angekommen.

Das braucht dann wahrscheinlich einfach noch ein wenig Zeit?
Oder auch Zwang - Zeit haben wir keine.

2. Interview with city development expert

Introduction provided to the expert

Background to the topic of the Matura thesis: Democratization of energy production and a possible future of autonomous supply for households in Switzerland: What are the technical possibilities and chances of feasibility regarding the democratization of energy production and a future autonomous supply for private households in Zurich?
Focus on urban development issues: The wider public is increasingly discussing energy supply issues that also have an impact on the development of the cityscape (solar installations, heat pumps, wind turbines, etc.), both at the level of commercial, but also small and micro installations by private households.

Interview Questions

- Are there scenarios in the urban planning of the city of Zurich for a significant expansion of energy generation systems for private households?
- If yes,
  - which areas and technologies are in the foreground?
  - what urban development and urban planning aspects need to be considered?
  - do these plans coincide with existing concrete demand from private individuals?
- If not, for what reasons?
- Are financial, ecological, or political/strategic considerations at the forefront when planning, issuing regulations or approving facilities for the city?
- From an urban planning expert's point of view, how should the (possible or existing) development be assessed? Should the aim be to increase energy generation by private households (assuming average residential and single-family households)?
- What are the limits and how are the interests weighted (cityscape, monument protection, consistency of building regulations, etc. vs. energy autonomy, CO_2 savings, etc.)?
- What role does politics currently play in this, and could it play in the future (subsidy measures, etc.)?

Personal interview with Silvia Banfi Frost, Energy Commissioner of the City of Zurich. December 04, 2023, (carried out in German, answers in black).

Gibt es in der städtebaulichen Planung der Stadt Zürich Szenarien für einen signifikanten Ausbau von Energiegewinnungs-Systemen von Privathaushalten?
Die Stadt Zürich hat das Ziel von Netto-Null, das heisst, dass man vollständig von den fossilen Energien wegkommt. Dies gilt für den Gebäudebereich, aber auch bei der Mobilität oder der Verbrennung von Abfällen, bei den Industrieprozessen etc. Bis zum Jahr 2040 müssen alle fossilen Brenn- und Treibstoffe durch Alternativen ersetzt werden. Konkret bedeutet dies, dass man auf andere Energiesysteme umsteigen muss, wobei für die Stromproduktion die Photovoltaik sehr wichtig ist. In der Schweiz ist die Stromproduktion bereits weitgehend CO_2-arm, durch die Nutzung von viel Wasserkraft und einem großen Teil Kernenergie. Durch die künftige Nutzung von Wärmepumpen und der Elektromobilität werden wir aber in Zukunft einen viel höheren Stromverbrauch haben, wobei der Zubau von Photovoltaik von zentraler

Bedeutung ist und wir ihn deshalb auf Stadtgebiet sehr unterstützen. Wir machen dies auf unseren stadteigenen Dachflächen, sind aber auch darauf angewiesen, dass die Potenziale auch auf privaten Dächern genutzt werden. Dabei hilft uns, dass durch das Energiegesetz des Kantons bei Neubauten eine Pflicht besteht, Photovoltaik-Anlagen zu erstellen. Bei der Sanierung von Dächern haben wir diese Pflicht jedoch noch nicht und wir würden sie uns wünschen. Was wir dafür haben, ist eine Förderung, mit der wir den Zubau von Photovoltaik auf privaten Dächern fördern und durch die Energieberatung unterstützen. Diese berät Interessierte, die sich überlegen, auf dem eigenen Dach eine Photovoltaikanlage zu bauen. Dabei wird das Potenzial bestimmt und das Vorgehen erläutert. Auf vielen Dächern ist es inzwischen nicht mehr notwendig, eine Baubewilligung einzuholen, sondern es muss nur noch gemeldet werden, was eine grosse Vereinfachung ist. Auf der anderen Seite kommt erschwerend hinzu, dass viele Gebäude unter Denkmalschutz stehen oder inventarisiert sind. Auf diesen Dächern braucht es nach wie vor eine Baubewilligung und Photovoltaik-Anlagen müssen auch speziell gestaltet sein, um auch den ästhetischen Aspekten Rechnung tragen.

Sehen Sie ein steigendes Interesse dieser dezentralen und autonomen Energiegewinnung bei Privatverbrauchern?

Wir sehen deutliche Steigerungsraten beim Ausbau der Photovoltaik, würden es jedoch gerne sehen, wenn bei Dachsanierungen grundsätzlich gleich eine Photovoltaikanlage gebaut würde. Da man ein Dach nur alle 30 bis 40 Jahre saniert, würde sich das anbieten. Wir sehen aber nicht nur grosses Interesse bei Privaten, sondern auch bei Firmen, eigene Photovoltaik-Anlagen zu installieren.

Gibt es in der städtebaulichen Planung Szenarien, welche Massnahmen man ausser der Photovoltaik treffen könnte, um das Energiegewinnungssystem zu optimieren?

In der Energieplanung haben wir zwei wichtige Massnahmen. Zum einen der Ausbau des thermischen Netzes. Zum Beispiel Energie-Verbünde, bei denen man Seewasser nutzt, um wie bei einer Wärmepumpe Heizenergie zu gewinnen und dieses dann mit Leitungen zu den Häusern bringt. Damit ersetzt man ebenfalls fossile Wärme, man braucht dazu aber den See und zusätzlichen Strom. Die zweite Massnahme liegt in der Stilllegung der Gasnetze. Damit sind die Verbraucher gezwungen, auf Wärmepumpen, Erdsonden oder eben thermische Netze umzusteigen. Dazu kommt die Förderung, zum Beispiel von Liegenschaften, die früher als notwendig eine Gasheizung oder eine Ölheizung ersetzen. Sie erhalten eine Entschädigung für die Jahre, in denen sie die Heizung noch hätten nutzen können, aber sie frühzeitig ersetzen. Daneben fördern wir Wärmepumpe und Erdsonde noch zusätzlich, wie auch den Anschluss ans thermische Netz.

Das deckt sich ja dann in den meisten Fällen mit dem, was die Privatverbraucher eigentlich auch anstreben?

In der Regel ja, wobei es auch Ausnahmen gibt. Es gibt immer auch Hausbesitzer und -Besitzerinnen, die an ihren bestehenden Heizungen hängen, inklusive Gas- oder Ölheizungen. Oder die ein geringes Bedürfnis haben, diese schnell zu ersetzen, da die Investitionskosten für eine Wärmepumpe oder für eine Erdsonde höher sind und damit der Anreiz für Eigentümer oder Eigentümerin diese Investition zu tätigen, nicht so groß ist.

Sie haben erwähnt, dass die finanzielle Komponente für die Privateigentümer auch sehr wichtig ist. Was steht denn für die Stadt im Vordergrund, wenn sie Vorschriften erlassen oder Anlagen bewilligen: sind das primär finanzielle, ökologische oder politisch-strategische Überlegungen? Zusätzlich gibt es ja auch Gebiete in der Stadt, wo man zum Beispiel keine Wärmepumpen bauen darf.

In der Stadt gibt es Gebiete, wo es wegen des Grundwassers nicht möglich ist, Erdsonden zu bauen. Es gibt andere Gebiete, wie zum Beispiel das Niederdorf, wo es keinen Platz für Erdsonden oder für Luft-Wasser Wärmepumpen gibt. Zudem ist dort die Bausubstanz alt, was zu einem hohen Energieverbrauch führt. In genau diesen Bereichen bauen wir die thermischen Netze aus, um den Leuten beim Umstieg zu helfen. In Gebieten, wo es gar keine Alternative gibt, können wir auch das Gasnetz nicht stilllegen, versuchen aber mit solchen zentralen Lösungen eine Alternative zu bieten.

Grundsätzlich steht bei der Stadt Netto-Null, also das Klimaschutzziel im Vordergrund und alle Massnahmen, die wir ergreifen müssen dem Klimaschutzziel dienen. Dabei müssen die Immobilienbesitzer und -Besitzerinnen ihren Teil leisten, wobei die Stadt Zürich viele Fördergelder vergibt, um den Heizungsersatz zu beschleunigen. Das neue Energiegesetz des Kantons ist sehr hilfreich, da es im Normalfall den Ersatz einer fossilen Heizung durch neue eine fossile Heizung verbietet. In der

Vergangenheit haben 80% der Immobilienbesitzer noch eine fossile Heizung eingebaut und seit dem Energiegesetz und der Vorschrift haben 90% erneuerbare Lösungen, mit Biogas sogar 95%.

Denken Sie, dass es mehr strikte Vorschriften bräuchte, um das Klimaziel zu erreichen, und wie realistisch schätzen sie es ein, dass es wird mit der bisherigen Entwicklung erreicht wird?

Persönlich denk ich, dass es Gesetze braucht. Die Stadt Zürich hat seit 2008 ein Klimaschutzgesetz, was nicht auf Netto-Null, sondern auf eine Tonne CO_2 bis 2050 abzielte. Allein das war schon recht strikt, da die ganze Mobilität, inklusive Flugverkehr dazugehörte. Trotz des Gesetzes ist wenig geschehen bis letztes Jahr das Energiegesetz in Kraft gesetzt worden ist. Anreize, Förderung, und Beratung sing gut, aber ein Gesetz wirkt schon sehr stark. Vielleicht erreichen wir 2040 Netto-Null nicht hundertprozentig, aber im Gebäudebereich werden wir sehr nahe dran sein, bei der Mobilität sieht es vermutlich ein wenig anders aus.

Denken Sie, dass die Stadt Zürich ein Vorbild für andere Städte sein kann und damit eine positive Kettenreaktion auslösen kann?

Davon kann man ausgehen und wir hoffen natürlich, dass Zürich als Vorbild dienen wird. Oft schauen die kleineren Gemeinden auf die grossen Städte, was funktioniert und was nicht - ich hoffe, dass wir auch im Bereich von Netto-Null ein gutes Vorbild sein können.

Sie haben schon den Denkmalschutz erwähnt, der die Möglichkeiten manchmal begrenzt. Was wären andere Grenzen, die das Erreichen des Klimaschutzziels erschweren?

Es geht um den Umstieg von fossilen (Energien). Die Stadt kann selbst verfügen, die Gasnetze stillzulegen. Dass jemand eine Ölheizung hat, können wir nicht verbieten und in Ausnahmefällen erlaubt der Kanton auch neue Ölheizungen. Technisch ist vieles möglich, aber es kann sehr teuer werden, wie im Fall der Spitzenlast. Während eine Heizung im Normalbetrieb ausreichen kann, wird zum Beispiel bei einer Kältewelle viel mehr Energie benötigt. Bei den erwähnten thermischen Netzen wird diese Spitzenenergie häufig noch mit fossilen Energien gedeckt. Das ist auch eine Kostenfrage und es wird sehr schwierig sein, diese Spitzenlast nicht mit fossilen Energien zu decken. Im Moment ist es noch häufig Gas, teilweise auch Öl, künftig könnte man vielleicht auch auf Biomasse umsteigen, es bleibt aber im Bereich der Gebäude eine große Herausforderung.

Es gibt diverse Länder, die versuchen, aus der Atomkraft auszusteigen. Die Atomkraftwerke in der Schweiz werden ja nicht mehr erneuert, sobald sie ihre Lebenszeit erreicht haben. Halten Sie das für problematisch? Ohne Atomkraftwerke fehlt uns doch wieder einiges mehr an Energie und wie sollen wir das ausgleichen, ohne wieder mehr auf fossile Brennstoffe zu setzen?

Beim Strom wird es absolut essenziell sein, auf die Erneuerbaren umzusteigen. Es wird aber nicht ausreichen, dafür haben wir auch sehr große Effizienzsteigerungspotenziale. Die Nachfrage (nach Strom) wird durch die Wärmepumpen und die Elektromobilität steigen, aber wir haben bereits heute erhebliche Stromsparpotenziale die wir nutzen könnten. Die Kombination aus Effizienzsteigerungen und starkem Ausbau aller Erneuerbaren, Photovoltaik, Wind wo möglich, aber auch Wasserkraft wird der Weg sein. Ich gehe nicht davon aus, dass in der Schweiz noch Atomkraftwerke gebaut werden.

Welche Rolle spielt die aktuelle Situation mit dem Krieg in der Ukraine? Motiviert das Privathaushalte, mehr auf andere Energien als Gas zu setzen, welches oft aus Russland kommt, um unabhängiger zu sein von anderen Ländern?

Absolut, letztes Jahr haben wir das stark gemerkt und als die Energiemangellage ein grosses Thema war, haben sehr viele Leute die Energieberatung aufgesucht, um sich über Energiesparmassnahmen zu informieren. Neben Krieg und Mangellage haben aber vor allem die hohen Preise als Treiber für den Umstieg auf erneuerbare Energien gewirkt.

Wäre denn eine Verteuerung der fossilen Brennstoffe eine Möglichkeit, die Leute aus finanziellen Gründen zum Umsteigen zu bewegen?

Eine CO_2 Abgabe haben wir ja bereits, auch auf Brennstoffen, allerdings ist sie nicht sehr hoch. Eine Verdoppelung des Benzinpreises würde sicher viel ausmachen, wäre allerdings auch schwierig, politisch umzusetzen. Statt mir Förderung mit einer Verteuerung des ungewünschten Verhaltens die Leute zum Umsteigen zu bewegen, hat man mit dem CO_2-Gesetz versucht, welches an der Urne von der Bevölkerung abgelehnt wurde.

Heute wird ja, wenn der Strom teuer ist, Schweizer Strom verkauft und exportiert und dann zu einem anderen Zeitpunkt billiger wieder importiert. Wie denken Sie, wird sich das in Zukunft entwickeln? Bei Stromimporten weiss man ja nicht, wie umweltfreundlich und CO_2-neutral dieser ist dann ist.
Das ganze Stromnetz ist ein europäisches Netz und wir sind im Winter schon lange auf Stromimporte aus dem Ausland angewiesen. Im Sommer exportieren wir viel Strom und im Winter importieren nicht nur Kernenergie, sondern zum Beispiel bei Wind auch billigen erneuerbaren Strom aus Windenergie aus Deutschland. Ohne Importe und Exporte werden wir sowieso nicht über die Runden kommen, da es für eine autarke Schweiz sehr viele Speicher bräuchte, die wir im Moment nicht haben. Die Wasserspeicher und Pumpspeicherwerke reichen nicht aus, um unseren Bedarf an Winterstrom zu denken. Natürlich bereitet es Sorge, dass in Frankreich noch so viele Kernkraftwerke in Betrieb sind und weitere geplant werden. Diese sind zwar CO_2-neutral oder CO_2-arm, bringen aber viele andere Probleme mit sich.

Wie wird sich nach Ihrer Einschätzung die Situation nach dem Erreichen des Klimaschutzziels in ca. 2040 weiter entwickeln? Wird es weitere Optimierungen geben und bis wohin schaffen wir es mit der dezentralen und autonomen Energiegewinnung?
Ich bin optimistisch, dass Produktionstechnologien verbessert und Speichertechnologien entwickelt werden, die helfen werden, den vollständigen Umstieg zu den Erneuerbaren und hundertprozentig fossilfrei zu erreichen. Eine Frage wird sein, ob wir es auch schaffen, die verbleibenden Emissionen und das (zivilisatorische) CO_2 aus der Atmosphäre zu entfernen, damit wir auch wirklich Netto-Null erreichen. Die Hoffnung ist auch, dass die Leute auch ohne Gesetze und Vorschriften handeln, denn eigentlich wissen wir, was wir zu tun haben. In der Stadt Zürich haben wir das Problem, dass sehr viele Mieter und Mieterinnen sind und die Hauseigentümerschaften nicht immer die richtigen Anreize haben. In selbstbewohnten Liegenschaften hat man mehr Anreize, entsprechende Investitionen zu tätigen. Zum Beispiel bei der Energieeffizienz, da bei einem nicht-effizienten Gebäude ja die Mieter und die Mieterinnen die Nebenkosten bezahlen. Daher wäre ein Gesetz zu begrüssen, das vorschreibt, dass bis 2040 die Gebäude saniert werden müssen.

Wäre es denn machbar, in der ganzen Stadt alle Gebäude zu sanieren, sodass sie energieeffizient wären? Nicht bis 2040, aber wenn es 2045 wäre, wäre es auch ja in Ordnung.

Können wir es damit schaffen, dass diese Privatverbraucher, diese Haushalte autonom werden?
Wenn wir ein sehr großes Gebäude haben, in dem unten beispielsweise eine Bäckerei ist, die sehr viel Energie verbrauchen, dann ist das Gebäude sehr wahrscheinlich (auch in Zukunft) nicht autonom. Aber das macht nichts, solange man alle Möglichkeiten nutzt, die man hat, bei der Fassade, beim Dach, bei der Energieeffizienz, mit Erdsonden usw. Und wenn es dann noch einen Zusatzverbrauch gibt, dann muss man diesen halt beziehen.

B. Abbreviations

ASHP	Air-Source Heat Pump
BEV	Battery Electric Vehicle
BFE	Federal Energy Department (Bundesamt für Energie)
CHF	Swiss Franc
COP	Coefficient of Performance
DER	Distributed Energy Resource
EKZ	Elektrizitätswerke des Kantons Zürich
EWZ	Elektrizitätswerke der Stadt Zürich
GIS	Geographical Information System
GSHP	Ground-Source or Geothermal Heat Pump
GWh	Gigawatt-Hour
IB	International Baccalaureate
J	Joule
kW	Kilowatt
kWh	Kilowatt-Hour
kWp	Kilowatt-Peak
MJ	Megajoule
PV	Photovoltaic Cell / Photovoltaic

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