E3S Web of Conferences **634**, 02001 (2025) https://doi.org/10.1051/e3sconf/202563402001
FCEE2025

Feasibility of the green transition and energy saving potential in buildings

Andrej Senegačnik[1*], *Martina* Zbašnik Senegačnik[2]

[1]University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia
[2]University of Ljubljana, Faculty of Architecture, Zoisova 12, 1000 Ljubljana, Slovenia

Abstract. The European "Green Deal" is an ambitious plan to phase out fossil and nuclear fuels in the near future, i.e. by 2050, and replace them with renewable energies (electricity, synthetic fuels, hydrogen, etc.). Despite years of efforts and extensive investment in renewable energy sources, their share of final energy is only increasing very slowly. The global share of renewable energies is less than 15 %. The development of renewable energy in Slovenia between 2003 and 2019 is analysed, where its share in primary energy has increased from ~10% to 20%, mainly due to the use of wood for energy. At the current level of consumption, a complete switch to green energy is neither technically nor economically feasible with the currently mature technologies. It is therefore necessary to look for solutions that also enable a reduction in energy consumption. One of these solutions for the building sector is passive house technology. The passive house is characterised by an extremely low heating energy consumption of a maximum of 15 kWh/m^2 per year. A practical example of energy use in a passive house is discussed. It is shown that the energy consumption in a passive house is only one third of the statistical average consumption.

1 Introduction

The European "Green Deal" [1] predicts very ambitiously how we in Europe will phase out fossil and nuclear energy and switch completely to renewable energy sources (RE). The plan is very tempting, but unfortunately it is not feasible in reality due to numerous technological obstacles for which we will not have adequate solutions in the near future. The demand for energy is growing rapidly, while the share of renewable energy sources is only growing very, very slowly. According to the International Energy Agency (IEA), global energy consumption in 1973, for example, was 254 EJ and the share of renewable energies was 12.3%. By 2023, global energy consumption had more than doubled to 620 EJ, and the share of renewable energy sources had risen to just 14.6%, despite huge amounts of money being invested in renewable energy. The world therefore still mainly uses fossil and nuclear energy sources, more than 85% in total. Energy consumption in Europe and North America is declining because goods are being imported from Asia (China, for example, produces 50% of the world's steel), which of course means higher global energy consumption. The second law of thermodynamics states that the entropy of a system can be reduced locally (e.g.

* Corresponding author: andrej.senegacnik@fs.uni-lj.si

through imports), but the overall entropy of the universe (the Earth) increases at the same time. With the green transition, we are trying to somehow circumvent this fundamental law of nature. We want to produce power from the environment in such a way that no traces remain in the environment. In the past, there has been a lot of talk about various new renewable energy technologies, of which only two reasonable technologies remain today, namely solar and wind energy technologies (this is also recognised by the IEA) [2]. The green transition will be based on the replacement of fossil and nuclear energy with electricity from renewable energy sources, which will lead to a significant increase in electricity consumption in the future compared to today. Various studies predict a four- to six-fold increase in electricity consumption [3].

2 Slovenia's energy balance

Slovenia is still heavily dependent on fossil and nuclear energy. Table 1 compares the situation in 2003 and 2019 (the last year in which the global COVID crisis, the Ukraine conflict, had no impact on energy consumption). Primary energy consumption increased by 4.5% in the period 2003-2019 [4], the share of renewable energy sources increased from ~10% to ~20%, mainly due to the energetic use of wood biomass. The share of imported energy was as high as 68.4 % in 2019. In the national statistics, nuclear heat is considered a domestic energy source (although the fuel is imported), which leads to an official import dependency of ~50 %.

Table 1: Primary energy balance for Slovenia [4]

	2003		**2019**		
Primary energy	**energy PJ**	**share %**	**energy PJ**	**share %**	**import PJ**
Coal	63.8	25.8	47.3	18.3	8.8
Petroleum products	95.5	38.6	98.5	38.1	98.5
Natural gas	38.0	15.3	30.3	11.7	30.3
Nuclear heat*	27.1	10.9	31.5	12.2	31.5
Hydro energy	10.5	4.3	16.9	6.6	-
Renewables	11.4	4.6	31.4	12.2	-
Industrial waste	1.0	0.4	2.5	1.0	-
Total	**247.3**	**-**	**258.5**	**-**	**169.1**
Total renewables		9.3		19.7	
Import share					68.4

*Slovenian share 50 % (50 % Croatia)

The first question of the green transition is therefore how to generate all the electricity needed to replace fossil and nuclear energy in the near future. Slovenia has limited possibilities to use some RE technologies [5]:

- Currently, a lot of wood biomass is used as an energy source, as Slovenia is a relatively forested country. Wood biomass currently accounts for ~13% of primary energy.
- Hydropower potential is already well exploited and currently accounts for around 5% of primary energy. An increase of around 20% is still possible.
- Geothermal energy is currently not suitable for generating significant amounts of electricity.
- Wind energy has no great potential. Only three wind turbines with a total capacity of ~4 MW are currently installed. Most of the sites suitable for thermal wind energy use are located in the 355 protected areas of "Natura 2000", where environmental regulations prohibit any

construction work or intervention in the area. If the selected sites are not part of the "Natura 2000" protected areas, the construction of wind turbines near urban areas always meets with strong opposition from the local population.

- Solar energy is best suited as a sufficiently large renewable primary source. For Slovenia, the use of photovoltaics (PV) solar power plants is currently the most suitable. The operation of solar power plants is characterised by the time-variable generation of electricity, as it depends on solar radiation. The term variable renewable energy (VRE) has recently been used for such sources.

2.1 PV solar power plants

For more than a decade and a half, the state has been promoting the installation of solar power plants on roofs (average subsides of ~250 EUR for produced MWh [6]). The results are rather modest. The annual production of solar power plants amounted to 361 GWh (1.3 PJ) in 2023 [7], which corresponds to only 0.64% of the final energy consumed in Slovenia [4]. As the share of time-variable generation increases and exceeds current demand, so does the need for storage, i.e. intermediate energy storage for uninterrupted supply of consumption at times when generation does not match consumption (e.g. at night, in winter). Electricity storage in large systems is currently one of the many major technological obstacles to the green transition. Electricity is a volatile form of energy and not a stored form, such as potential energy. The above problem is currently solved by converting electricity into another type of (stored) energy that can be stored. Technologically, there are several possibilities - in batteries in the form of chemical potential, in the form of compressed air in caverns, conversion to hydrogen, etc. As a technologically mature technology, pumped storage power plants (PSHP) are best suited for long-term storage, also in Slovenia. The solution seems quite simple, but the storage needs are so large that the implementation for a complete green transition is not feasible. The volumes of water that would need to be pumped daily exceed the water content of Slovenian rivers, and therefore the only option would be to implement a PSHP that utilises the sea and pumps seawater into the Karst Rim, which is geodetically ~400 m higher, ~10 km from the sea, and 1 m^3 of water stores ~1 kWh of electricity. For seasonal storage, a water volume of 10.2 km^3 would be required, e.g. a circular reservoir with a diameter of 20.8 km and an active height of 30 m. The proportionality of the reservoir size in relation to the Slovenian area is shown in the figure 1. The details of the calculation are presented in the article by A. Senegačnik and M. Sekavčnik [8].

Fig. 1. Size of the upper reservoir of the pumped storage power plant for the "full green transition" [8]

Even a very partial implementation of the green transition without corresponding system services, such as energy storage, strengthening the transmission grid, ensuring grid stability and many other reasons listed in [9], has proven to be questionable in practice. Germany has come the furthest in this type of experiment, to the point where the price of electricity has risen so much that it has also affected the competitiveness of the economy. To name just a few basic characteristics of the German electricity system: average daily peak power 60-70 GW, installed PV plant capacity 94.3 GW, wind power plants 71.7 GW [10]. German VRE sources are thus installed for more than three times the average daily peak, but their share in the annual final energy balance is less than 9% [10, 11]. If it stays at 9 %, what happens if this share doubles to 20 %? Most of the factors that should be taken into account to determine the actual total price of electricity from renewables are described in [9].

2.2 Potential for reducing energy consumption

Energy demand is increasing at local and global level despite the commitments signed to reduce it. In view of today's energy consumption and the use of technologically mature technologies, a full replacement with renewable energies does not make sense [8]. The solution to the problem must be sought on the energy consumption side and not in satisfying our endless greed for more and more energy. As long as there are no technological solutions to generate and store the required amounts of energy from renewable sources, we need to think about reducing the demand for energy.

For most of human history, primary energy consumption has been linked to the provision of food and has been constant, but in recent centuries it has risen sharply due to demand in industry, transport and the service sector, and energy demand in the buildings we live in is also increasing. Figure 2 shows primary energy consumption by sector in different historical periods and in different countries or regions of the world. In recent decades, consumption has increased primarily in industry, transport and the service sector, and energy consumption in households has also risen considerably. In Slovenia, this averages 27.1 GJ (7,540 kWh) per capita per year [4].

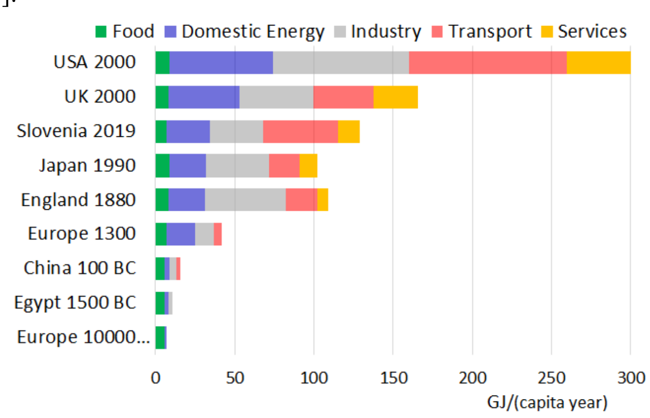

Fig. 2. Annual primary energy consumption per capita by purpose in different time periods and locations [4, 12]

As individuals we do not have much influence on a large part of the energy demand in society, we can reduce the demand in the transportation sector to a certain extent and in the buildings we live in to a large extent. Nowadays, home comfort is associated with almost constant temperatures indoors throughout the year, heating buildings in winter and cooling them in summer are unavoidable costs for every household. The fact is that every additional degree in winter means a 5-10 percent higher heating bill. Buildings are therefore a major energy consumer, so it makes sense to look for energy savings in the home.

2.2.1 Passive house – the optimal energy-efficient building

The energy efficiency of buildings is not a new concept; passive houses have also been built in Slovenia for more than 15 years. The passive house standard enables very large energy savings in heating [13]. Instead of several hundred kilowatt hours per square meter per year, a passive house consumes less than 15 kWh/(m^2 a), which in fuel terms means about 1.5 litre of heating oil per square meter of heated area per year. Since 2008, when the state began to promote the construction of passive houses, more than 3,000 houses have been supported with non-repayable subsidies. Investing in a passive house is not significantly different from building according to the current rules for the efficient use of energy in buildings, but is currently of a higher quality.

Fig. 3. Passive house in Ljubljana (Slovenia), in January 2024 in foggy and cloudy weather [14]

2.2.2 Planning, construction and operation of passive houses

Achieving the passive house standard is influenced by several parameters [13]. The first measure to reduce energy consumption is to take the natural conditions of the location into account when planning a passive house. A suitable orientation of the building enables the living spaces to be heated with solar energy that enters through the glazing. The building envelope must be designed and constructed airtight (n_{50} = 0.6 h^{-1}) and thermal bridge free ($\Psi \leq 0.01$ W/(m K)). Elements of walls, roofs and floor slabs must have a heat transfer coefficient of $U \leq 0.1$-0.15 W/(m^{2}K). Passive houses must have windows with triple glazing ($U \leq 0.8$ W/(m^{2}K)). Most building technologies are suitable for passive houses. The choice depends on the personal preferences of the building owner, and often also on the price. The same results can be achieved with solid and lightweight constructions as well as with different materials.

In order to achieve the lowest possible ventilation heat losses, a controlled ventilation system with heat recovery of the exhaust air is mandatory in a passive house. The air in passive houses is always fresh. With consistent planning and construction of a passive house, the need for additional heating is very low. Such a low heating requirement is usually covered by a heat pump, but other heating systems are also suitable.

2.2.3 Practical example – operating energy of a passive house in Ljubljana

We investigated the operating energy of a passive house made of wood in Ljubljana, Figure 3. Ljubljana (Slovenia) is located in temperate climate zone (46 °N, 15 °E), temperatures in summer up to +35 °C, in winter down to -10 °C and in a climatically unfavourable zone due to frequent winter fog and low cloud cover. The 190 m^2 heated areas are heated by underfloor heating and the heat is supplied by an air-to-water heat pump. In the transitional seasons, the rooms are heated using solar energy. The heating costs are very low and are included in the electricity costs. The electricity supplies all systems in the house: ventilation and heating system, lighting, hot sanitary water, all appliances in a four-person household (refrigerator, two freezers, washing machine, household appliances, stove for regular cooking, frequent use of the oven, television and some computers that are in use most of the day). The energy consumption for heating after the project is 9.6 kWh/(m^{2}a) [14]. Throughout 2023, four people lived in the house and consumed electricity to live more or less in the same way.

The cost of electricity consumption depends on the time of year and especially on the solar energy available during the heating period. Table 2 shows the electricity consumption in 2023. In the cold months (November, December, January, February) with less sunny weather (lots of fog and low cloud cover) and low temperatures, the average monthly electricity consumption was around 500 kWh (in January, the maximum, 555 kWh). From May to October, monthly consumption fluctuated between 215 kWh and 255 kWh [14]. In sunny weather, regardless of the season and outside temperatures, the heat pump only operates very little. In 2023, the coldest months were January (average temperature 3.8 °C) and February (average temperature 3.6 °C) [15]. February had the most cold days, almost twice as many as January, and more than three times as much solar radiation. For this reason, 65 kWh less electricity was consumed in February than in January.

The passive house in Ljubljana has a very good thermal envelope, the ceiling to the roof is insulated with 50 cm of thermal insulation made of glass wool with a thermal conductivity of λ = 0.032 W(m K), so there are no problems with excessive overheating even in the summer months. Although the heat pump enables reversible operation, i.e. cooling in summer, this was not used in five summers. When the temperature in the house rose to the limit of thermal discomfort, the heat wave was always interrupted by summer storms.

Table 2: Meteorological data and energy use in a passive house [14, 15]

2023	Average temperature. °C	Monthly solar radiation h	Number of cold days < O °C	Number of hot days ≥ 30 °C	Number of hot nights ≥ 20 °C	Monthly electricity consumption (kWh)
January	**3.8**	**38.6**	9	0	0	**555**
February	**3.6**	**129.4**	**17**	0	0	**490**
March	8.6	149.9	4	0	0	313
April	10.2	162.5	3	0	0	307
May	15.9	179.1	0	0	0	255
June	21	275.7	0	0	0	245
July	22.7	278.4	0	13	1	235
August	21.8	262.2	0	12	2	250
September	19.1	218	0	0	0	215
October	15	121.7	0	0	0	240
November	6.9	94.2	4	0	0	380
December	4.3	50.8	11	0	0	**510**
Total						**3995**

In the winter months, the monthly electricity bill was a maximum of EUR 122, in the summer between EUR 50 and 55. The difference between the annual and winter electricity consumption is the energy used for heating.

In 2023, the operation of a passive house in Ljubljana consumes 3995 kWh of electricity, i.e. 1000 kWh per person, which means ~2500 kWh of primary energy with a Slovenian "power plant mix" (~1/3 heat, ~1/3 water, ~1/3 nuclear power, 5-30% imports). Roughly speaking, this is three times less than the statistical annual consumption of 7540 kWh per capita (household consumption) in Slovenia, which is shown in Figure 2. If this saving were calculated at the level of the country of Slovenia, it would mean ~36 PJ, which corresponds to 14% of primary energy in 2019. These are idealized calculations of savings that cannot be achieved in reality due to the extraordinary investments in replacing old residential buildings with new ones. With an annual replacement rate of 2 % of old buildings with new ones, 100 % replacement would be achieved in 35 years.

3 Conclusion

The European "Green Deal" is a very ambitious EU environmental plan that assumes that EU countries will achieve climate neutrality with zero greenhouse gas emissions without nuclear and fossil energy by 2050 by switching to renewable energy sources. The strategies and scenarios for the green transition are written in a very populist and politically palatable way. In reality, especially in the case of Germany, it has been shown that the price of electricity has increased so much that the impact on the competitiveness of the economy became visible when the share of variable renewables reached ~10% of final energy. The prediction of green policy was exactly the opposite, that energy would become cheaper? A complete green transition is not possible with this level of energy consumption and with existing mature technologies [16, 17].

The building sector offers great potential for savings. The energy consumption of a single-family passive house in Slovenia, in an area with a temperate climate, at a location with relatively low solar radiation in winter and an average outside temperature of ~0 °C, is analysed. The building was constructed according to the passive house standard (heating energy consumption of no more than 15 kWh/m^2 per year). The passive house in Ljubljana has a very well insulated, airtight and thermal bridge-free envelope, a built-in ventilation system with heat recovery and is heated with an air-to-water heat pump. The electricity requirement for operating the building in 2023 is shown, which shows that the electricity consumption for operating the heat pump depends not only on the outside temperature, but also on solar radiation. The heating costs are limited to four winter months with cloudy and foggy days and are very low, the electricity consumption for heating is ~1 MWh in 2023.

The energy efficiency of buildings therefore represents a suitable potential for energy savings in households. The "greenest" and cheapest energy is that which we do not need and have not consumed.

References

1. European Commission, European Green Deal. (2019) https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691
2. IEA Publications, Renewables 2023, Analysis and forecast to 2028, (2024) https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf
3. J. L. Holechek,; H. M. E. Geli, M. N. Sawalhah, *Sustainability*, **14**, 4792 (2022), https://doi.org/10.3390/su14084792

4. Government of the Republic of Slovenia, Energy balance of Republic of Slovenia (Slovenian), (2003-2021), https://www.energetika-portal.si/dokumenti/statisticne-publikacije/letna-energetska-bilanca/
5. A. Senegačnik, R. Stropnik, M. Sekavčnik, S. R. Oprešnik, U. Mlakar, Š. Ivanjko, U. Stritih, *Sustainable Cities and Society*, **96**, 104668 (2023) https://doi.org/10.1016/j.scs.2023.104668
6. Borzen, Subsidies for solar power plants for individuals, (2024) https://borzen.si/sl-si/podpore-za-zelene-investicije/subvencije-za-soncne-elektrarne-za-fizicne-osebe
7. Slovenian Energy Agency, Report on the energy sector in Slovenia for 2023, (2024) https://www.agen-rs.si/web/en/publications
8. A. Senegačnik, M. Sekavčnik, Strojniški vestnik - Journal of Mechanical Engineering **70,** 9-10, 405-416 (2024), DOI:10.5545/sv-jme.2024.1007
9. L. Schernikau, W. H. Smith, R. Falcon, *Journal of Management and Sustainability,* **12**, 96-121 (2022) https://doi.org/10.5539/jms.v12n1p96.
10. Electricity maps, State Germany, (2024), https://app.electricitymaps.com/zone/DE,
11. European Commission, EU Energy in figures, Statistical Pocketbook 2023 (2023), https://south.euneighbours.eu/publication/eu-energy-in-figures-statistical-pocketbook-2023/
12. V. Smil, *Energy and Civilization,* MIT Press, Cambridge (2017) http://dx.doi.org/10.7551/mitpress/10752.001.0001
13. What is a Passive House? (2024) https://passipedia.org/basics/what_is_a_passive_house
14. Personal communication, Operating data of passive house (2024)
15. Slovenian Environment Agency, Meteorological data for Ljubljana, (2024), https://meteo.arso.gov.si/met/en/
16. J. Dujardin, A. Kahl; B. Kruyt, S. Bartlett, *Energy,* **135**, 513–525 (2017) http://dx.doi.org/10.1016/j.energy.2017.06.092
17. S. Honga, S. Qvistb, B. W. Brook, (2018) *Energy Policy*, **112**, 56–66 (2018) http://dx.doi.org/10.1016/j.enpol.2017.10.013.