Basic and recommendations on electricity mix models and their application in buildings LCA

A Contribution to IEA EBC Annex 72

February 2023

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Preface

This publication is an informal background report. It was developed as part of the international research activities within the context of the project IEA EBC Annex 72. Its contents complement the report “Context-specific assessment methods for life cycle-related environmental impacts caused by buildings” by Lützkendorf, Balouktsi and Frischknecht et al. (2023). The sole responsibility for the content lies with the author(s).

Together with this report, the following background reports have been published on the subject of “Assessing Life Cycle Related Environmental Impacts Caused by Buildings” (by Subtask 1 of IEA EBC Annex 72) and can be found in the official Annex 27 website (https://annex72.iea-ebc.org/):

- Survey on the use of national LCA-based assessment methods for buildings in selected countries (Balouktsi et al. 2023);
- Level of knowledge & application of LCA in design practice: results and recommendations based on surveys (Lützkendorf, Balouktsi, Röck, et al. 2023);
- Basics and recommendations on modelling of processes for transport, construction and deconstruction in building LCA (Soust-Verdaguer et al., 2023);
- Basics and recommendations on influence of service life of building components on replacement rates and LCA-based assessment results (Lasvaux et al., 2023);
- Basics and recommendations on influence of future electricity supplies on LCA-based building assessments (Zhang 2023);
- Basics and recommendations on assessment of biomass-based products in building LCAs: the case of biogenic carbon (Saade et al., 2023);
- Basics and recommendations on influence of future climate change on prediction of operational energy consumption (Guarino et al., 2023);
- Basics and recommendations on discounting in LCA and consideration of external cost of GHG emissions (Szalay et al., 2023);
- Basics and recommendations on aggregation and communication of building LCA assessment results (Gomes et al. 2023);
- Documentation and analysis of existing LCA-based benchmarks for buildings in selected countries (Rasmussen et al., 2023);
- Rules for assessment and declaration of buildings with net-zero GHG-emissions: an international survey (Satola et al. 2023).

Summary

The evolution of electricity systems is one of the key issues to progress towards net zero GHG emissions, as shown in the IEA roadmap for the global energy sector[1]. Because a large part of the produced electricity is consumed in buildings, and because electricity consumption is an important contributor in life cycle impacts of buildings, it is essential to properly account for the electricity system when performing a Building LCA.

This document was written for method and tool developers, and policy makers (regulation). Existing (official and individual) approaches in different countries are first reviewed. Users are invited to follow the recommendations provided by the developers (e.g. certification scheme, design tools). Some of the recommendations are case specific. We propose to distinguish the following four cases:

a. Assessments against benchmarks defined by voluntary certification schemes and regulation
b. Environmental reporting of facility management companies and assessment of private lifestyles:
c. LCA in building design tools (building optimisation independent of voluntary schemes or regulation)
d. LCA in building research

These recommendations address electricity related impacts. Methodological choices should be consistent across energy sources. Thus, the following recommendations should be applied on fuels as well. For instance, if a future renewable scenario is applied for electricity production, the same level of ambition should preferably be applied for gas (future supply with biogas and/or synthetic gases produced with biogenic carbon and renewable electricity) and liquid fuels.

Even if it is sometimes difficult to express recommendations that are relevant in all situations, this document explains the choices made in different contexts. The following Table 2: Synthesis tabl an overview of the recommendations. To ensure transparency in LCA results, the assessment method of electricity related emissions must be described by indicating clearly the corresponding methodological choices.

Table S: Synthesis of the 10 recommendations. "Gray" indicates than no specific choice is recommended.

Type of choice	**Application cases**			
	Regulation/ certification	Design tool	Facility assessment	Research
1_Generic vs provider-specific electricity mix	generic	generic	specific	
2_Geographic scope	national	national	national	
3_Production mix vs supply mix	supply mix	supply mix	supply mix	
4_Nature of trade flows	commercial or physical flows, explain the choice			
5_Modelling choice for the supply mix	production-export+import or production+import, explain the choice			
6_End uses dependence	universal if same temporal variation in buildings as national consumption, use-specific recommended otherwise (e.g. winter peak demand for heating)			
7_Time dimension	present, near future or long-term future mix, explain the choice			
8_LCA modelling approach	average, short-term marginal or long-term marginal, explain the choice			
9_Time granularity	annual or hourly, explain the choice			

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[1] IEA (2021), Net Zero by 2050, IEA, Paris https://www.iea.org/reports/net-zero-by-2050

Annexes present in more detail models corresponding to different temporal resolution (from hourly to annual), models used in national methods, example methodological choices in various tools, and models for local renewable electricity production (particularly photovoltaics).

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Abbreviations

Abbreviations	Meaning
ADEME	Agency for energy management and environment (France)
AIB	Association of Issuing Bodies
BAU	Business As Usual scenario
BIPV	Building Integrated Photovoltaics
BREEAM	Building Research Establishment Environmental Assessment Method
BWR	Boiling Water Reactor technologies
CCS	Carbon Capture and Storage
CED	Cumulative Energy Demand
DGNB	German Sustainable Building Council
DHW	Domestic Hot Water
EAM	European attribute mix
EEMM	European Electricity Market Model
EKZ	Energy company for the canton of Zurich
ELCAB	Electricity in Life Cycle Assessments of Buildings
ENTSO-E	European Network of Transmission System Operators for Electricity
GHG	Greenhouse Gas
GOs	Guarantees of Origin
HP	Heat Pump
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LEED	Leadership in Energy and Environmental Design
NEP	Energy policies
NRE	Non-Renewable Primary Energy
NVEs	Norwegian Energy Regulatory Authority
POM	Political Measures
PV	Photovoltaic
PWR	Pressurized Water Reactor
RE	Renewable Primary Energy
RE-DISS	Reliable disclosure systems for Europe
REKK	Regional Centre for Energy Policy Research
RSP	Renewable Portfolio Standard
RTE	French Transmission System Operator
SFOE	Swiss Federal Office for Energy
TMY	Typical Meterorological Years
TSO	Transmission System Operators
Abbreviations	Meaning

UCTE	Union for the Co-ordination of Transmission of Electricity
WWB	Business as usual
ZEB	Zero-Emission Buildings

Definitions

Electricity production mix: % of different processes from which electricity is produced. For instance the global world electricity production mix in 2020 is[2] : 35% coal, 29% renewables, 23% gas, 10% nuclear and 3% others.

Electricity supply mix: % of different processes from which supplied electricity is produced.

Specific mix: supply mix of a specific electricity provider

Generic mix: average supply mix of all electricity providers

Use-specific mix: supply mix for a specific use (e.g. heating, cooling, lighting…)

Universal mix: average supply mix for all uses

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[2] https://www.iea.org/data-and-statistics/charts/global-electricity-generation-mix-2010-2020

1. Introduction

The evolution of electricity systems is one of the key issues to progress towards net zero GHG emissions, as shown in the IEA roadmap for the global energy sector[3]. Because a large part of the produced electricity is consumed in buildings, it is useful to address related models in the Annex 72 methodology reports.

Electricity consumption during the operation of buildings is one important factor determining the environmental impacts, greenhouse gas emissions and primary energy demand during its life cycle. The assessment of one, rather energy efficient, building with electricity being the only energy carrier consumed during its operation by several research organisations using their respective national method revealed two things: firstly, the operation phase contributes at least one third to the total greenhouse gas emissions; secondly, the differences in life cycle greenhouse gas emissions vary by a factor of more than 5 (see **Error! Reference source not found.** and report of activity 1.2,Frischknecht et al. 2019).

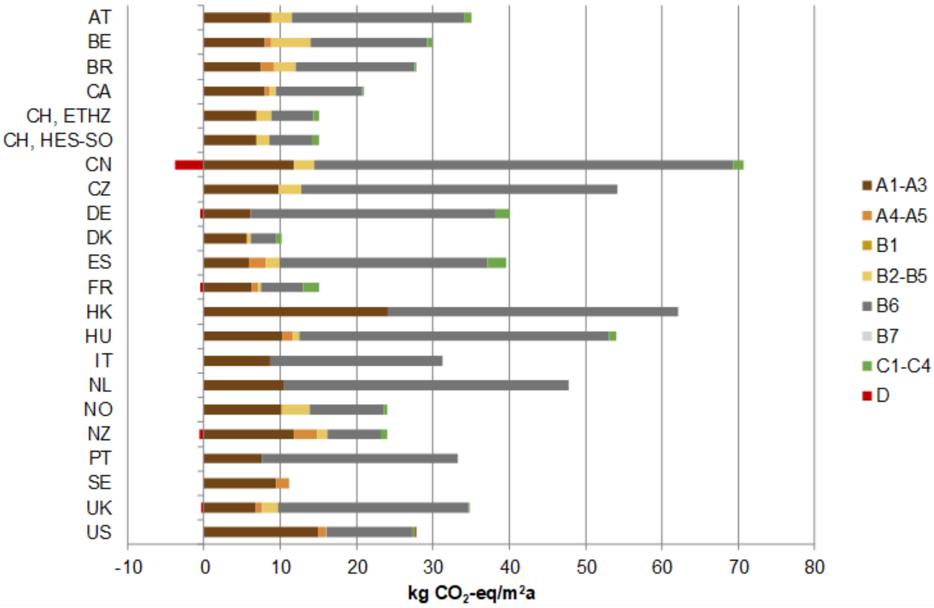

Figure 1: Greenhouse gas emissions in kg CO_2-eq. per m^2 and year of the reference building “be2226” assessed according to the national/regional approaches of the countries listed,Frischknecht et al. 2019.

The provenience and the technologies used to generate the electricity are key determining factors for the greenhouse gas intensity of electricity. That is why it is considered very important to choose the most appropriate electricity model in the life cycle assessment of buildings.

Temporal variation of the electricity production mix and related impacts may be large in some countries. For instance, in France CO_2 emissions are higher during peak demand due to the operation of thermal power plants during these periods. **Error! Reference source not found.** (Roux et al. 2016b) shows the difference in environmental impacts per m^2 and year of electricity use in a so called “plus energy house” when applying an hourly mix (plain line) and a yearly average mix method (dotted line), respectively in the case of electric space heating (a) and all uses including a PV production (b). Compared to modelling electricity supply on a yearly average basis, an hourly based electricity mix increases the space heating related CO_2 emissions of the building per m^2 and year by 20% in graph a) and the whole electricity related emissions with PV production by 40% in graph b). The difference is more pronounced with building integrated PV because more PV

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[3] IEA (2021), Net Zero by 2050, IEA, Paris https://www.iea.org/reports/net-zero-by-2050

electricity is produced than consumed in summer and the excess production is fed into the grid (which potentially gives rise for avoided emissions[4]) and more electricity is consumed than produced in winter and the greenhouse gas emission intensity of the avoided electricity mix during summer is lower than that of the consumption during winter.

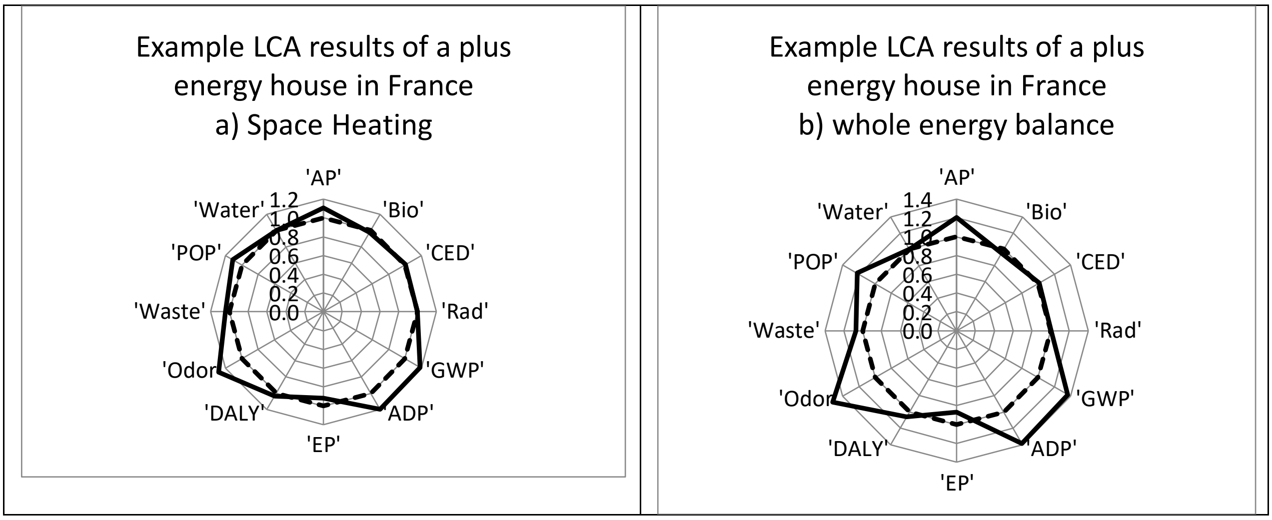

Figure 2: Impacts of electricity use in a Plus energy house in France (Roux et al. 2016b), Comparison between an hourly mix (plain line) and a yearly average mix method (dotted line)

Considering an average or a longterm marginal electricity mix may also have a large influence on the resulting environmental impacts of a building, e.g. the carbon footprint of a house comparing electric and natural gas heating as shown in **Error! Reference source not found.** (Roux et al. 2016a). Two aspects are varied and combined into four future scenarios: climate change (temperature rise; 1 and 2) and legal framework (A and B): Climate change is more severe in scenarios 1 than in scenarios 2, A corresponds to business as usual and B to more renewables and carbon tax.

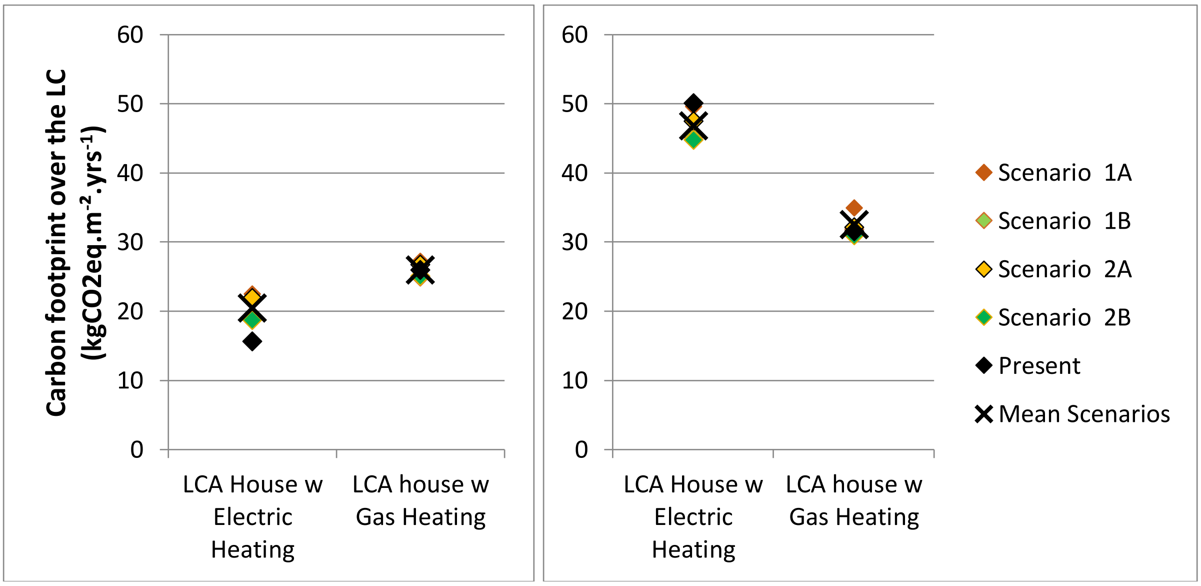

Figure 3: CO2 emissions of a house considering natural gas or electricity alternatives for space and water heating (Roux et al. 2016a), using an attributional (left) or a consequential approach (right)

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[4] This is one possible modelling option, see Chapter XXX on « exported energy » for a discussion on the various approaches.

In this case, the choice between attributional or consequential LCA reverts the ranking of the alternatives and thus may change the decision between natural gas and electric heating. The choice of one particular long term scenario has less influence on the emission intensity and no influence on the ranking.
The question of long term technology development occurs with material manufacture (including resource extraction), technical performance of building elements such as windows or photovoltaic panels and fuel supply chains and finally electricity mix and power plant performance. This chapter focuses on modelling the electricity mix during the operation of buildings. That is why technology developments in other fields related to buildings are not covered in this chapter.

The background report is structured as follows: In Chapter **Error! Reference source not found.** an overview of main questions related to the design of buildings are listed. Chapter **Error! Reference source not found.** contains the state of art of scope dependent modelling electricity mix in the operation phase of buildings in different countries. Chapter 4 contains a description of the proposed harmonised approach for each of the five questions and Chapter **Error! Reference source not found.** contains illustrations of the proposed scope dependent harmonised approaches. In Annex A in Chapter 0, the different basic types of electricity mixes are explained and Annex B in Chapter 0 contains descriptions of the most recent national electricity mixes according to the typology described in Annex A.

2. Status of Discussion and Questions

The considerations in this Chapter are limited to the question of the electricity mix appropriate to be used in the environmental assessment of buildings. Hereby it is proposed to distinguish the following application oriented questions:

1. Quantify the environmental impacts of a building and compare it to national benchmark values (in view of certification or labelling) – based on conventions/agreements (Special case: proof/certification of (net) zero GHG emission buildings)

2. Quantify the environmental impacts of different alternatives for a given building specification and use this information to select and build one of the alternatives.

3. Identify the optimum (minimum) environmental impacts of construction and dismantling of the building on one hand and operation of the building on the other (trade off).

4. Assess whether to act now or to wait for better (less electricity consuming) technologies based on a comparison of the environmental performance of different options.

5. Calculation of environmental payback time in the case of investment measures which lead to reduced electricity demand in the use phase (electricity demand in operation or maintenance).

We did not identify research work on nor applications answering questions 4 and 5. We therefore do not address them in this report.

3. Existing (official and individual) Approaches in Different Countries

3.1 Introduction

Environmental life cycle assessment is applied on buildings and provides answers to the different questions listed in Chapter **Error! Reference source not found.**. In this subchapters the state of application of environmental assessments of buildings in different countries is described, grouped according to the five main questions identified.

3.2 Benchmarking for Buildings

3.2.1 Denmark

In current building code, only the operational phase of buildings is considered. However, the building authorities have introduced a voluntary sustainability class, including requirements for LCA of buildings. It was implemented as a set of voluntary requirements in May 2020, and which are planned to be implemented as a part of the building code in January 2023. In order to prepare for the introduction of LCA in the building code, development of an LCA tool for buildings was initiated by the authorities. Thus the national tool, LCAbyg has been developed and several analyses have been and are being performed in order to develop benchmarks.

The LCA benchmarks for buildings that are alrady in use in Denmark relates to DGNB certification. DGNB has been used in Denmark since 2012. From the beginning, an Excel tool developed by the Danish Building Research Institute was used for performing LCA, applying static energy approach for the operational energy. The final results from the tool were based on a combination of two reference study periods:

a. 50 years calculating both embodied impacts and impacts related to the operational energy. The results weighting 70% of the final result.
b. 80-120 years calculating only the embodied impacts. The results weighing 30% of the final result.

In year 2015, the LCAbyg tool was released in order to prepare for the voluntary sustainability class in the building code, and since 2018, DGNB certifications can be performed with either the Excel tool (and the RSP and energy approach described above) and LCAbyg (with RSP and energy approach described below). The aim is that LCA for future DGNB certifications will be performed in LCAbyg and according to similar methods and requirements as introduced in the voluntary sustainability class.
For several years, the recommended reference study period for building LCA in Denmark has been from 80 to 120 years depending on the building type (Aagaard et al. 2013). **Error! Reference source not found.** shows the reference values for the embodied GHG emissions, according to DGNB 2018. The voluntary sustainability class has introduced the use of a reference study period of 50 years, and the DGNB will use the same in the newest update of DGNB 2020 manual by the end of 2020. The voluntary sustainability class introduced in May 2020 does not include reference values. However, the necessary analysis to prepare for the possibility to include benchmarks have been conducted and published (Zimmermann et al., 2020). Here, reference values for both embodied and operational impacts together and separated have been calculated. DGNB will be using these analyses to prepare updated reference values for the DGNB 2020 manual.

Table 1: RSP and reference values for LCA in DGNB, when LCAbyg is used for certification in DGNB 2018 manual (Rasmussen & Birgisdottir 2018; Rasmussen et al. 2019)

		Reference values (GHG emissions)	
New buildings	RSP (years)	Construction	Operation
Modules according to EN 15978		A1-A3, B4, C1-C4	B6
Residential buildings	120	6,0 kg CO_2/m^2/year	The reference values for B6 is dynamic and depending on both building type and building specific supplementary demand. In addition, the emissions are based on a forecasting scenario for the future electricity supply.
Office buildings	80	5,3 kg CO_2/m^2/year	

The building code determines the energy requirements for buildings, which differentiate by building type. By regulation, some buildings are allowed an additional supplementary demand. The supplement is assigned for buildings with e.g. extended in-use hours, extra lighting and/or ventilation demand and extra floor height. The data for the environmental impacts of the operational energy in LCAbyg represent the Danish energy grids and includes data for the average Danish electricity production, district heating and natural gas for heating, which were developed for LCAbyg (COWI 2016, COWI 2020). LCAbyg allows the user to choose between the use of static energy data based on dataset from year 2015 and forecasting of electricity and district heating according to the political goals until year 2050 (Birgisdottir & Rasmussen 2019). The forecasting scenario is based on estimation of the expected development of the energy composition in 5 data points (2015, 2020, 2025, 2035 and 2050) and the corresponding expected environmental impacts (see Section 0). Use of the forecasting scenario for energy use is required when performing LCA in the voluntary sustainability class and DGNB.

Since the recommended reference study period in building LCA in Denmark has until May 2020 been from 80 to 120 years depending on building type, a building LCA scenario calculated in 2018 represents a period ending in 2098-2138. In the forecasting scenario, data for 2050 is used for the remaining years after year 2050.

Error! Reference source not found. shows the results for the greenhouse gas emissions for a typical office building calculated in LCAbyg based on the approach described above (Birgisdottir & Stenholt Madsen 2017).

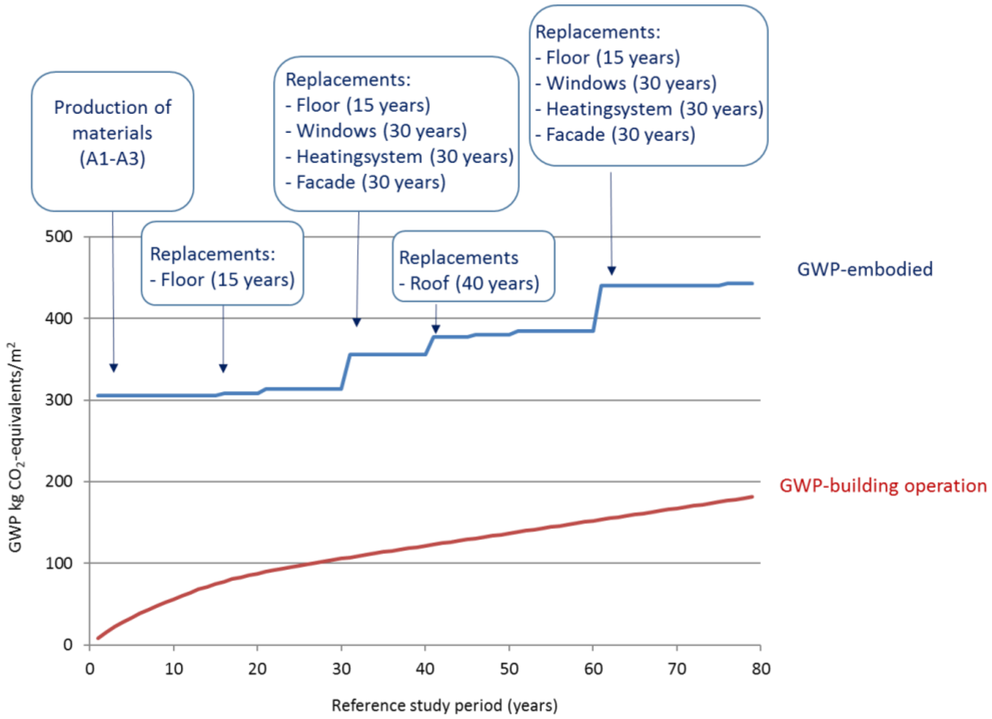

Figure 2: Greenhouse gas emissions for an office building, results accumulated over the reference study period of 80 years. Blue line showing the embodied greenhouse gas emissions (A1-A3, B4, C3-C4), red line showing the GHG emissions from the operational energy use (B6) - (Birgisdottir & Stenholt Madsen 2017)

3.2.2 France

Two main approaches were developed. One as a voluntary label in order to study the next building regulation, and one as a design tool aiming at a more science based evaluation.

In the "E+C-" label[5] which will be the basis for the next building regulation "RE 2020", a recent electricity mix is used but in order to account for the temporal variation of this mix, it is different for heating, cooling, domestic hot water, lighting and other uses, for housing and tertiary buildings. There are two benchmark levels regarding CO_2 equivalent (GHG) emissions per m^2 of building, C1 and C2, which depend on the type of building (houses, apartment buildings, offices and other buildings), the climate zone (North of France, Mediterranean coast etc.). The threshold for the next regulation is not chosen at the moment.

In the EQUER design tool, part of the Pleiades software used by 2,500 users (engineers, architects, contractors, teachers, students etc.) and approved e.g. in the BREEAM label, there are two possibilities regarding the electricity mix: one corresponds to a recent annual average electricity mix (e.g. for 2017), and the second to an hourly electricity mix model (see annex A §1.6.5). Benchmarks have been elaborated for three building types: single family houses, apartment buildings, and office buildings. There are two performance levels for each type, corresponding to the best and worst performance of the sample on each LCA indicator (per m^2 and per year), so that a designer knows how his/her project performs compared to references. Each performance level has two possible values: one corresponds to the recent annual average electricity mix, and the second to an hourly electricity mix model as the user can choose between these two options.

3.2.3 Hungary

In current building energy regulations, only the operational phase of buildings is considered. There are different primary energy requirements for residential buildings, offices, educational buildings and a reference building approach is used for other building uses. Primary energy demand is calculated using primary energy

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[5] E+C-: means: higher energy efficiency, lower CO2 emissions

factors. For electricity, there are two factors available for peak and off-peak use. These factors are not entirely based on physical flows, but also involve some political and energy strategy considerations. The next revision of the building code is in progress. It is expected that besides primary energy factors also a CO_2 emission indicator will be introduced and there is a recommendation to base these values on a life cycle approach. There is no intention, however, to include the construction phase in the short-term, although this has been recommended by researchers.

In current Hungarian LCA studies, an annual average electricity mix is used for benchmarking.

3.2.4 Switzerland

The SIA technical bulletin 2040 (SIA 2017), a voluntary standard, regulates the procedure for determining the greenhouse gas emissions and the primary energy demand, non renewable for the construction (construction, servicing and deconstruction including waste management), the operation (energy requirements for heating, hot water, ventilation, lighting and operating equipment) and the daily mobility induced by the building. For each of the three components reference values are given which serve as benchmarks. The benchmarks do not have to be met individually but help identifying where measures to improve the energy efficiency or reduce greenhouse gases are most needed. The target values for the primary energy demand, non-renewable and the greenhouse gas emissions correspond to the sum of the reference values of the three components. The SIA bulletin 2040 defines target and reference values as well as additional requirements for residential buildings, office buildings, school buildings, specialist shops, grocery shops and restaurants, both for new and retrofit buildings. Table 1 shows the greenhouse gas emission target and reference values and additional requirements for new buildings.

The modelling of the construction phase is done according to the technical bulletin SIA 2032 “Embodied energy: Life cycle assessment of the construction of buildings” (SIA 2020) and the modelling of the building induced mobility is based on the technical bulletin SIA 2039 “Mobility – energy demand in function of the building location” (SIA 2016).

Table 1: Reference and target values for greenhouse gas emissions in kg CO_2-eq per m^2 energy reference area and year, applied on residential, office and school buildings, specialists and grocery shops as well as restaurants, both new and retrofit. Reference service life: 60 years
Additional requirement: partial sum of “construction” and “operation” shall not exceed the amounts listed in this column

New buildings	Construction	Operation	Mobility	Total	Additional requirement
Modules according to EN 15978	A1-A3, B4, C1-C4	B6	not available		A1-A3, B4, B6, C1-C4
Residential buildings	9.0	3.0	4.0	16.0	12.0
Office buildings	9.0	4.0	7.0	20.0	13.0
School buildings	9.0	2.0	3.0	14.0	11.0
Specialist shops	9.0	6.0	6.0	21.0	15.0
Grocery shops	9.0	29.0	20.0	58.0	38.0
Restaurants	9.0	10.0	24.0	43.0	19.0

The target and reference values published in the technical bulletin SIA 2040 are aligned with the 2050 milestone target of a 2000-watt society (EnergieSchweiz für Gemeinden et al. 2014a, b).

Electricity used during the operation phase of a building is modelled using the Swiss average annual supply mix, excluding renewable electricity sold with dedicated, certified electricity products. In case the electricity consumption of a building is covered with certified renewable electricity and this supply is guaranteed with longterm contracts, the environmental profile of this certified electricity may be applied on up to 50 % of the total electricity consumption of the building. For the remaining share the environmental profile of the Swiss average annual supply mix applies (SIA 2017, clause 2.3.1.4).

In situ production of electricity and electricity consumption of the building are balanced on an annual basis. In situ produced and exported electricity has the environmental impacts of the in situ production. Exported electricity does not give rise for any environmental benefits from potentially avoiding electricity production elsewhere (see also Chapter XXX on exported electricity and Chapter XXX on zero emission building definitions).

The only instance where future developments are partly taken into account is daily individual mobility: the passenger cars are supposed to have a fuel efficiency of 3 litres gasoline per 100 km, which is about half of the current specific fuel consumption (according to New European Driving Cycle) of new passenger cars registered in 2019 in Switzerland.

3.2.5 Sweden

Sweden does not currently have a fully standardized approach for building LCA. Assessments are meant to follow the standards EN 15804 and EN 15978, but there is still room for manoeuvre regarding methodological choices in building LCA. Several significant initiatives can however be noted.

First, a mandatory declaration of greenhouse gas emissions for all new buildings has been introduced in 2022 (Swedish National Board of Housing, Building and Planning, 2018). This declaration, at the time of its introduction, will be limited to the impact of the product and construction stages (modules A1-5). Currently (during Spring 2020), a new proposal is being developed, regarding the future implementation of a mandatory declaration based on a more complete LCA. However, decisions regarding which life cycle stages to include and regarding methodological choices for this LCA declaration have not yet been taken.

Second, a number of voluntary certification systems are currently used on the Swedish market. The most used certification system in Sweden is Miljöbyggnad (Sweden Green Building Council, 2017). Miljöbyggnad is not based on an LCA approach, but the latest version (3.0) includes a criterion related to the calculation of greenhouse gas emissions from the building frame for modules A1-A4. The Nordic Swan Label for Buildings (Nordic Ecolabelling, 2016) does not either include an LCA-based assessment of greenhouse gas emissions. The LEED points system rewards initiatives that carry out an LCA and initiatives that show a 10% reduction in several impact categories compared to a reference building defined by the architect. However, there are not many methodological specifications as long as the same LCA method is used for the baseline and the reference building (United States Green Building Council, 2018). The BREEAM-SE system includes an assessment of energy performance, and a separate assessment of life cycle environmental impacts limited to construction materials (BRE Global & Sweden Green Building Council, 2017). Overall, none of the certification schemes commonly used in Sweden include an assessment of greenhouse gas emissions from operational energy use.

Third, actors from the building and infrastructure industry are contributing to the national initiative “Fossile Free Sweden” (Fossilfritt Sverige[6]). This voluntary initiative entails the development of a roadmap aiming for a climate neutral building sector by 2045, as well as a harmonized life cycle-based method to assess greenhouse gas emissions from building sector companies and individual measures or projects. As of Spring 2020, discussions are ongoing regarding various methodological aspects of this upcoming common assessment method, including how to assess greenhouse gas emissions from electricity and district heating.

Finally, new and upcoming certification systems will include a more complete life cycle assessment, including greenhouse gas emissions from operational energy use. The Citylab certification system for neighbourhoods was launched at the end of 2019. It includes, among other criteria, limit values for greenhouse gas emissions from operational energy use per dwelling in residential buildings, and per m^2 heated area in other facilities (excluding lighting and office equipment) (Sweden Green Building Council, 2019). The recently introduced

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[6] http://fossilfritt-sverige.se/fardplaner-for-fossilfri-konkurrenskraft/fardplaner-for-fossilfri-konkurrenskraft-byggbranschen/

$NollCO_2$ (Zero CO_2) certification system includes an assessment of life cycle greenhouse gas emissions (Sweden Green Building Council, 2020). Following guidelines from the Swedish Energy Agency, the assessment of greenhouse gas emissions from electricity use in Citylab and the pilot version of $NollCO_2$ is based on a yearly Swedish electricity mix, calculated following the method of the EU Joint Research Center (JRC) (Moro & Lonza, 2018). The original JRC calculation was based on values for 2013. In $NollCO_2$, the JRC method is used to calculate updated emission factors for electricity, for the year 2018. In a previous pilot version of $NollCO_2$, the assessment was meant to be based on a hourly Nordic electricity mix instead.

3.3 Comparison of Alternative Concepts (e.g. architectural competition)

3.3.1 Denmark

Alternatives can be compared with LCAbyg, by using static energy approach vs. forecasting (for electricity and district heating), and by looking into the consequences of different energy supply for heating (district heating, natural gas, electricity). Figure 1 shows an example where calculations of the consequenses of using static vs. forecasting approach for both electricity and district heating have been calculated in a report about embodied energy and GHG emissions (Birgisdottir & Stenholt Madsen 2017).

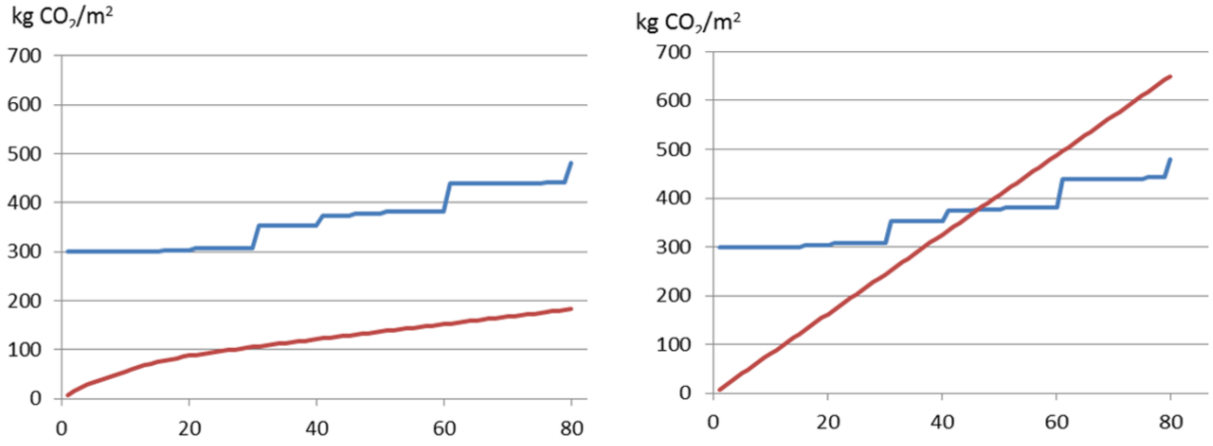


Figure 1: Embodied GHG emissions for an office building calculated over 80 years reference study period using forecasting scenario vs. static energy approach (Birgisdottir & Stenholt Madsen 2017).

If comparisons of alternatives are performed, they are most probably done in relation to DGNB certification or in research projects. However, there are no known documented examples of comparisons of alternative concepts for energy scenarios.

3.3.2 France

Alternatives can be compared either using the E+C- scheme (present electricity mix according to the building type and use of electricity) or the EQUER model (considering an annual average or an hourly model), see benchmark.

3.3.3 Hungary

Alternatives are generally compared using a recent annual average electricity mix. In architectural competitions, application of a LEED/Breeam rating scheme is sometimes required.

3.3.4 Switzerland

The technical bulletin SIA 2040 “SIA energy efficiency path” offers a calculation device for the early design stage which is being used to assess alternative concepts, for example submitted in an architectural competition. Hence the methodology specified in the technical bulletin SIA 2040 is also applied in comparisons, which implies that it is common practice to apply the average annual Swiss supply mix in comparisons of alternative concepts and architectural competitions.

Yet, depending on the context of use, other modelling approaches of the electricity mixes can also be relevant. In that context, two application cases are presented below to illustrate the influence of alternative modelling approaches for the comparison of design alternatives:

- Use of the current average annual Swiss supply mix (SIA 2040 approach) vs. the use of longterm consequential & residual mixes
- Use of the current average annual Swiss supply mix (SIA 2040 approach) vs. the use of an hourly Swiss supply mix

Application case 1:

In a project commissioned by a Swiss municipality the question was analysed and answered about the appropriate electricity mix to be used when comparing the environmental impacts of different strategies retrofitting existing buildings. In its ordinance, the municipality adheres to the 2000 Watt and 1 ton CO_2-eq-society. The city-owned public utility is vertically integrated (owns and runs power plants and power lines) and relies heavily on renewable energy. It is recommended to apply consequential electricity mixes complementary to the traditional attributional annual average electricity mix because the traditional approach favours inefficient retrofitting solutions. Energy inefficient buildings would however counteract the efforts of reaching 2000-Watt-society goals and lead to a substantial increase in electricity demand.

The environmental assessment of the decision about the appropriate measures in a retirements home owned by a Swiss municipality has been performed using consequential (long term marginal) electricity mixes. The retirements home has a gross and energy reference area of about 10’000 m^2 and an energy demand today of 435 MJ/m^2a for space heating and 50 MJ/m^2a for hot water supply. In a retrofitted state (new triple glazed windows, insulation of rooftop, façades and ground floor, ventilation with energy recovery), the energy demand is 68 MJ/m^2a for space heating, 50 MJ/m^2a for hot water supply and 10 MJ/m^2a electricity for ventilation. Electricity demand for further equipment (lighting, elevators) is disregarded for the sake of simplicity.

The climate change impact as well as the overall environmental impacts differ substantially depending on the electricity mix used (see

Figure 2, Frischknecht 2016). It shows that the solution of just replacing the heating system (from district heat to a heat pump operated with green electricity, the standard electricity product of this municipality) would be most beneficial, whereas retrofit solutions (substantially increasing the energy efficiency of the building) show higher impacts than the current situation. In its constitution the municipality committed itself to the 2’000 Watt society and a 1 ton CO_2-society, goals which are out of reach if the buildings are not refurbished, including an increase in their energy efficiencies. The utility of the municipality forecasted its electricity production and supply volume in 2050. The different scenarios show that natural gas fired power plants will be used in case the annual electricity demand is higher than the production capacity of renewables available.

Hence, favouring low energy efficiency building solutions contradicts the overarching goal of the municipality and urges the utility to purchase fossil based electricity or invest in fossil fuelled power plants. An assessment using longterm marginal electricity mixes is appropriate which shows the environmental benefits of retrofitting in comparison to solutions with just substituting the heating system.

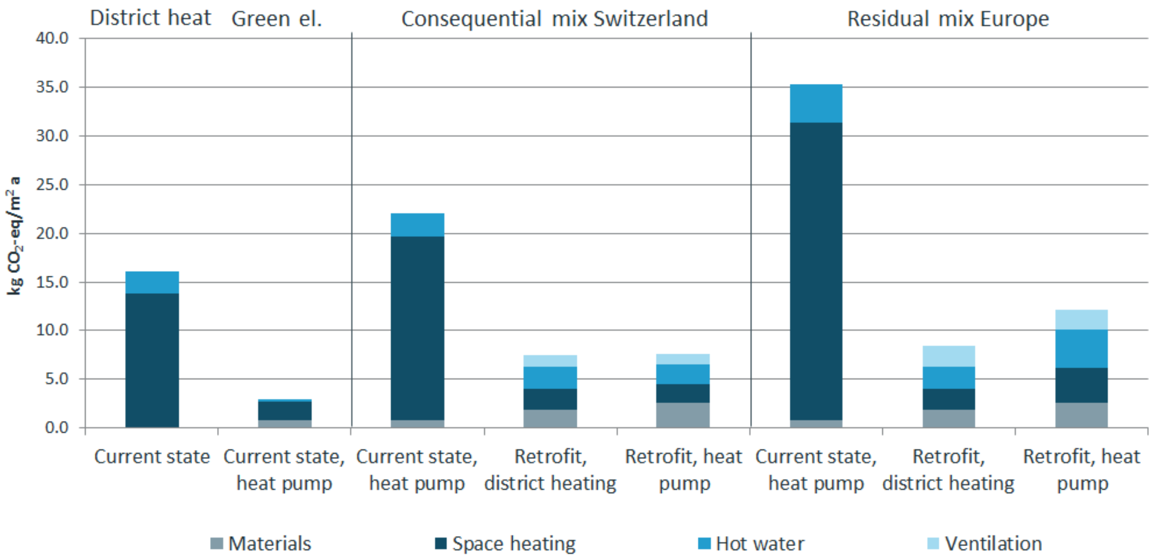


Figure 2: Greenhouse gas emissions of a retirements home in a Swiss municipality (Frischknecht & Stolz 2015), in kg CO_2-eq/m^2 and year

A similar effect can be observed when quantifying the overall environmental impacts according to the ecological scarcity method 2013 (Frischknecht & Büsser Knöpfel 2013).

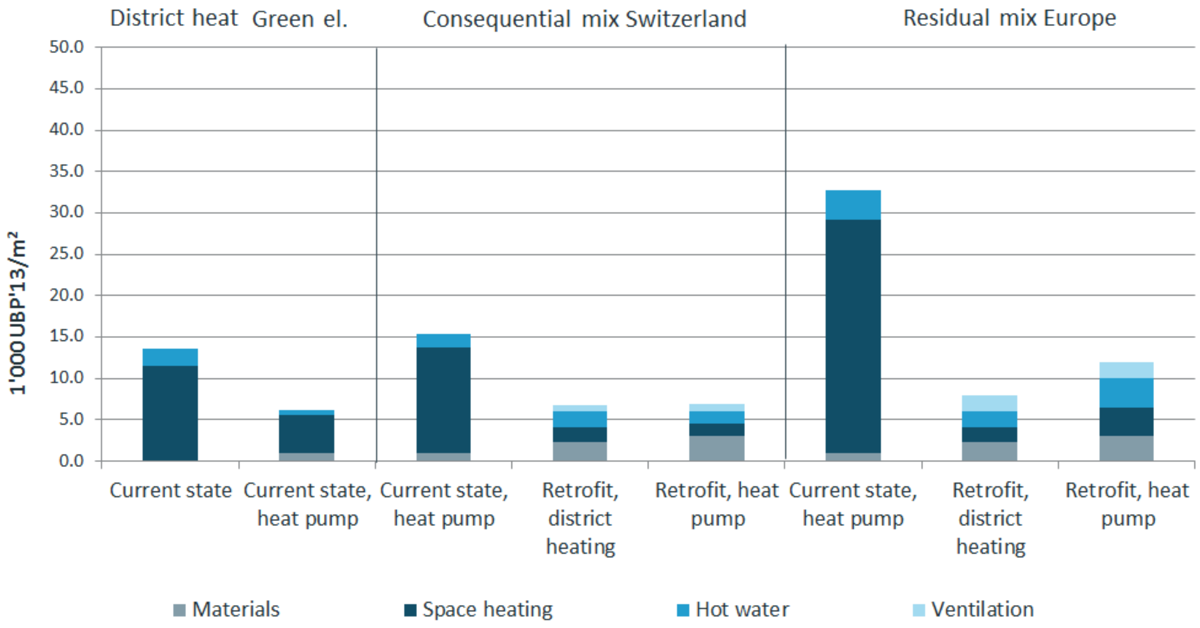


Figure 3: Overall environmental impact of a retirements home in a Swiss municipality (Frischknecht & Stolz 2015), in UBP/m^2 and year, ecological scarcity method 2013 (Frischknecht & Büsser Knöpfel 2013)

Application case 2:

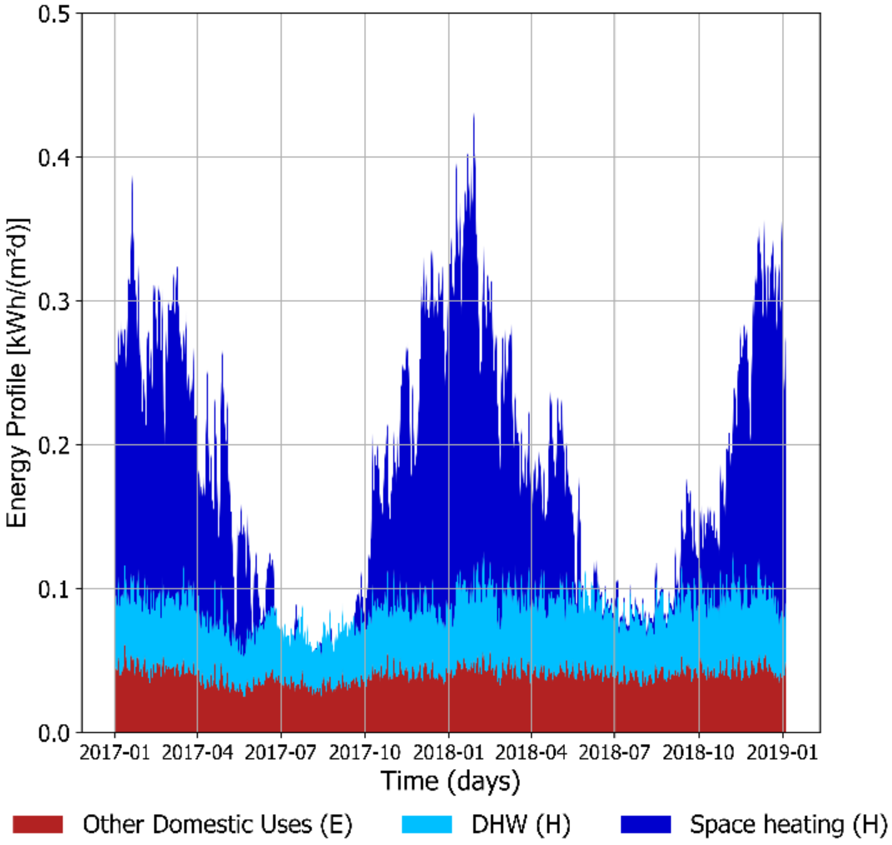
The case study is based on the results of the EcoDynBat research project funded by the Swiss Federal Office of Energy in 2018-2020. It aims at assessing the influence of the various intra-annual time steps of the environmental impact of the energy demand in the Swiss buildings (i.e., monthly, daily and hourly time steps).

Background research question & motivations:

The methodology for the electricity mixes in buildings specified in the technical bulletin SIA 2040 is used for both benchmarking purpose[7] and comparisons of design alternatives. In each of these contexts, it is a common practice to apply the average annual Swiss supply mix according to the KBOB 2009/1:2016 data. However, such approach does not provide the carbon emissions at a higher time resolution of the year (month, day or hour). Such approach may however be relevant to compare different energy supply for buildings (decentralized or from the grid). For the supplied electricity mix, in winter a substantial share of electricity is imported from Germany to fulfil the demand. It is thus important to know the level of "carbon" emissions in the electricity used in Swiss buildings (e.g., to cover the space heating) at each hour, day and month of the year.

A preliminary study, focusing on the determination of the hourly Swiss supply mix, already showed the high variability of the hourly GHG emissions during the year[8]. In order to obtain this hourly profile, the electricity mix has been calculated with a matrix-based computational approach considering the physical flows for the mix calculation and gross cross boarder exchanges (see description in the section 1.7.5), leading to significantly different results than the actual reference values used in the SIA 2040 technical bulletin in Switzerland.

Then these hourly electricity mixes with different time steps have been applied to different building case studies in order to check the LCA results of the electricity used. To do so, a multi-family building composed of 20 apartments is used as an exemplary case study. The electricity mix data is based on the 2017 and 2018 years. Building measurements were taken every hour, for the energy consumption of the 20 apartments and more specifically for the energy of the heating system (kWh), the total energy (kWh), the electricity (kWh) and the domestic hot water - DHW (L). The energy profile is given in the Figure 4:



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[7] See the details in section 1.3.2, Switzerland

[8] cf. **Figure 20** page 46 page where the GHG emissions of the Swiss supply mix are presented for different time steps is presented

Figure 4: Swiss MFH consumption profile considered for the EcoDynBat case study

Based on this energy demand profile, four scenarios were considered, Table 2:

Scenario	**Heat pump**	**District heating network**	**PV**		**Grid Electricity**	Time step
			Yes	**No**		
Reference		Heatingt & DHW		🟧	🟧	Annual, monthly, daily, hourly
B		Heatingt & DHW	🟧		🟧	
C	Heating & DHW			🟨	🟨	
D	Heating & DHW		🟦		🟦	

Table 2: Scenario considered for the time step influence within the Swiss project EcoDynBat

The reference case corresponds to the current building situation. The energy for space heat and DHW is provided by a district heating network operated by a gas fuelled cogeneration unit. The electricity is consumed from the grid. The case B adds a photovoltaic (PV) installation of 21kWp to cover the entire roof surface (all other things being equal as the reference case). Thus the PV self-consumption will decrease the amount of electricity imported from the grid. The scenario C assumes the use of an air-water heat pump (HP) to supply energy for space heat and DHW. For each time step, the HP performances (COP) are calculated as a function of the heat source and the distribution temperatures. The electricity is taken from the grid. Finally, the scenario D uses HP but, an additional PV installation (21kWp) is added, reducing the electricity consumed from the grid.

For all scenarios, the impacts of the electricity from the grid is considered according to the method and results (for the LCA data of the electricity supply mix) presented in the chapter 1.7.5.

Table 3 presents the LCA results of scenarios A, B, C, and D for the different time steps (yearly, monthly, daily and hourly) for the following indicators:

- greenhouse gas emissions (GHG),
- non-renewable primary energy (NRE),
- Renewable Primary energy (RE)
- Total environmental impact (UBP) according to the Ecological Scarcity method 2013

Figure 5 graphically reports the relative time step influence on the GHG emissions for the four scenarios[9].

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[9] Relative time step influence is calculated by comparing the hourly, daily and monthly results to the reference yearly result

		Annual			Sum	Monthly			Sum	Daily			Sum	Hourly			Sum
		Other Domestic Uses	DHW	Space Heating		Other Domestic Uses	DHW	Space Heating		Other Domestic Uses	DHW	Space Heating		Other Domestic Uses	DHW	Space Heating	
Reference	**GHG**	2.36	4.34	8.95	**15.65**	2.23	4.34	8.95	**15.52**	2.3	4.34	8.95	**15.59**	2.3	4.34	8.95	**15.59**
	NRE	89.27	73.48	151.39	**314.14**	85.28	73.48	151.39	**310.15**	87.95	73.48	151.39	**312.82**	89.83	73.49	151.39	**314.7**
	RE	35.41	0.49	1	**36.9**	36.42	0.49	1	**37.91**	35.73	0.49	1	**37.22**	35.61	0.49	1	**37.1**
	UBP	3934.58	2657.03	5474.14	**12065.75**	3713.58	2657.03	5474.14	**11844.75**	3895.89	2657.03	5474.14	**12027.06**	3884.44	2657.029	5474.14	**12015.609**
Scenario B	**GHG**	1.93	4.34	8.95	**15.22**	1.913	4.34	8.95	**15.203**	1.97	4.34	8.95	**15.26**	2	4.34	8.95	**15.29**
	NRE	62.21	73.48	151.39	**287.08**	59.99	73.48	151.39	**284.86**	61.4	73.48	151.38	**286.26**	63.95	73.48	151.39	**288.82**
	RE	46.38	0.49	1	**47.87**	46.88	0.49	1	**48.37**	46.48	0.49	1	**47.97**	46.02	0.49	1	**47.51**
	UBP	3318.8	2657.029	5474.12	**11449.949**	3208.72	2657.03	5474.14	**11339.89**	3343.31	2657.029	5474.14	**11474.479**	3363.88	2654.03	5474.14	**11492.05**
Scenario C	**GHG**	2.36	1.34	2.94	**6.64**	2,23	1,3	3,14	**6,67**	2,3	1,34	3,25	**6,89**	2.3	1.34	3.4	**7.04**
	NRE	89.27	35.66	81.64	**206.57**	85,27	34,15	79,75	**199,17**	87,95	35,3	81,4	**204,65**	89.83	31.16	87.72	**208.71**
	RE	35.41	14.13	32.32	**81.86**	36,42	14,5	32,45	**83,37**	35,73	14,2	31,92	**81,85**	35.61	14.21	30.42	**80.24**
	UBP	3934.6	1783.97	4023.72	**9742.29**	3713,6	1703	3968	**9384,6**	3895,89	1790	4257,56	**9943,45**	3884.44	1780.03	4370.8	**10035.27**
Scenario D	**GHG**	2.03	1.23	2.96	**6,22**	0.75	2	1.23	**6,29**	2.08	1.25	3.14	**6,47**	2,1	1,26	3,29	**6,65**
	NRE	68.18	28.44	75.95	**172,57**	7.47	65.71	27.44	**167,36**	67.32	28.13	75.68	**171,13**	70,07	29,31	81,72	**181,1**
	RE	43.96	17.06	34.62	**95,64**	66.27	44.51	17.26	**96,52**	44.06	17.07	34.26	**95,39**	43,62	16,98	32,78	**93,38**
	UBP	3454.4	1622.7	3953.5	**9030,7**	1154.2	3331.5	1570.4	**8758,2**	3485.1	1644	4118.5	**9247,6**	3502,5	1645,1	4225,7	**9373,3**

Table 3: Results of the EcoDynBat case study for the assessment of the time step influence on the environmental impacts of the energy consumed in a MFH building located in Switzerland

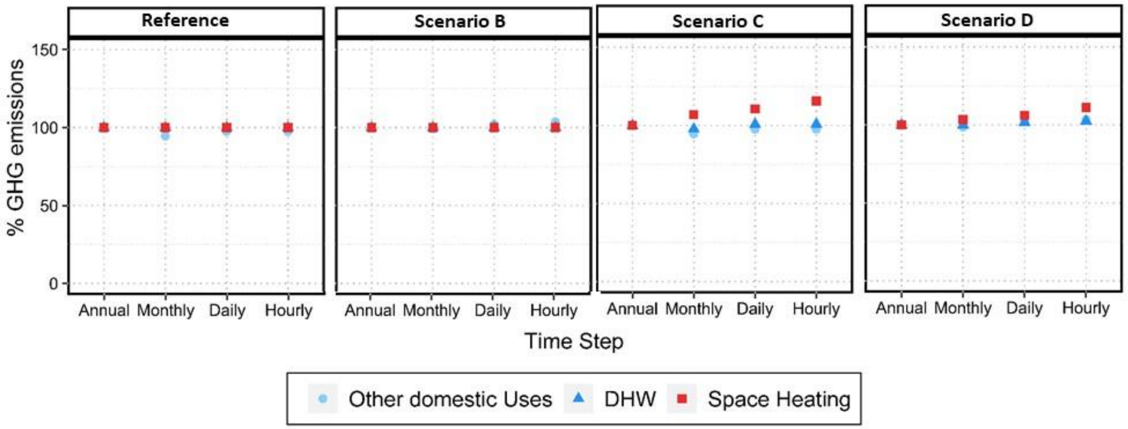

Figure 5: Influence of the time step for the four scenarios for the GHG emissions

According to the results presented in the **Table 3**, the time step influence is found to be very small for the NRE, RE, and UBP indicators for all the scenarios. As a result, calculating on an annual basis according to the SIA 2040 provide a sufficient accuracy.

For the GHG emissions, the impacts are found to be slightly more influenced by the time step choice, see **Figure 5**. Influence depends on the energy uses and scenarios. The time step influence is more important in scenarios C and D, where the electricity is used for all the uses (including the heating, DHW and the other uses), than in the reference scenario and in scenario B, where the electricity is used only for the other uses.

The detailed interpretations are reported below:
In the reference scenario, supplied by a district heating network operated with a gas cogeneration unit, the time step influence for the other electricity uses is 2.5% when considering the hourly time step compared to the yearly time step. For the total building energy demand, the overall time step influence drops to only 0.3%.

For the case B, i.e reference case + PV, the time step influence is about 3.5% (hourly compared to yearly) at the maximum for the other domestic uses which also negligible. For the total building energy demand, the deviation between an hourly and annual balance decreases to 0.5%.
Thereby, it appears that the time step influence is small when considering the domestic appliances electricity demand solely and when the space heating & DHW is supplied by a non-electric energy carrier. Moreover, the electricity demand related to the domestic uses is not fluctuating over the year and thereby an annual time step is sufficient to perform the calculation.

Regarding two other scenarios (C & D), the trends are similar for the relative deviations for the other electricity uses (about 2.5% to 3.5% in the two scenarios). The time step influence between an hourly and an annual balance is again not significant for these uses. The situation is however different for the space heating.

In scenario C, where the space heat and DHW is supplied by an air/water HP and thereby electricity, the variation for the space heating is now found to be 13.5% when considering the hourly rather than the yearly step. The DHW impact is not influenced by the time step. Globally, regarding the overall impact of the energy demand, the time step influence is found to be 5.7% since the space heat electricity demand represent 42% of the overall building energy demand.

Regarding the scenario D, i.e. scenario C + PV, the difference between hourly to annual is found to be 10%. On the overall energy demand impact, the time step influence is 6.5% because the PV also influence the impacts related to the domestic use and DHW electricity demand.

These results confirm that the choice of the time step can be rather influential when the electricity demand show a high seasonality. In the case study, the building is recent and has a low energy demand profile. For renovated buildings with higher energy demand for space heat, the time step could thereby be more significant.

Considering the four indicators used in the EcoDynBat project and in the case of Switzerland and its electricity supply mix pattern the electricity demand seasonality will drive the time step influence only for the GHG emissions. High seasonality usage and high share of this usage (such as for a renovated building operated with a HP) may significantly influence the time step while, logically, the impact of a constant electricity demand will not be influenced by any time step consideration.

Finally, from the EcoDynBat project, it can be also stated that the assumptions regarding the electricity mix is key and strongly influence the environmental impacts of the supply electricity mix. This aspect is one of the key outcome of the EcoDynBat project.

Application case 3: ELCAB

Goal of the case study:
The case study is based on the results of the ELCAB (**E**lectricity in **L**ife **C**ycle **A**ssessments of **B**uildings) research project funded by the Swiss Federal Office of Energy in 2018-2020 (Frischknecht et al. 2020). Similar to the EcoDynBat project it aims at assessing different electricity mix models on the environmental impact of the electricity demand in Swiss residential and office buildings.

Several electricity mixes were defined and established. In particular, annual and seasonal electricity mixes were derived matching the hourly generic use profile of a residential and an office building with the technology mix producing the electricity in Switzerland and the technology mixes used to produce the electricity imported from neighbouring countries. The building specific annual electricity mixes are compared to the Swiss electricity mix matching the national hourly consumption profile with the technology mixes as decribed above, to the Swiss consumer and supply mixes based on guarantees of origin 2018, to the average future Swiss electricity mix 2020-2050 (to cover 30 years of operation of a building erected today), to a long term marginal power plant technology (natural gas fired gas combined cycle power plant), and to the mix 2017 of the city of Zürich.

Furthermore, the influence of self generation of electricity with PV system and of on site battery storage on the specific electricity mix of the residential building was evaluated and quantified.

On the basis of the life cycle inventories established the specific environmental impacts of these electricity mixes were quantified. Finally, the different electricity mixes were applied in the use phase of the life cycle assessments of a residential and an office building to show the consequences of the choice of the electricity mix model on their environmental performance.

Methods:
Several electricity mix models were developed and applied in this project:

1. Annual and seasonal attributional electricity mixes of Switzerland in 2018. These electricity mixes were established by determining the hourly production, subtracting the hourly commercial exports and adding the hourly commercial imports of Switzerland. The resulting technology mix profiles were matched with the load (consumption) profiles of a residential and an office building (see Figure 6**Error! Reference source not found.**) and with the consumption profile of Switzerland in 2018. The technology mixes of the imports and the exports represent the country mix of the respective hours.
2. The Swiss consumer mix based on guarantees of origin 2018, the Swiss supply mix based on guarantees of origin 2018[10] and the ewz (utility of the City of Zürich) electricity mix based on guarantees of origin 2017.
3. The average future electricity mix of Switzerland according to the “New Energy Policy” scenario of the Energy Strategy 2050 was determined in 5 years time steps from 2020 until 2050. It does not include commercial trade but only imports required to satisfy the domestic demand.
4. The long term marginal electricity mix of Switzerland and of ewz was derived comparing the electricity demand and production volumes of the Business as Usual and the New Energy Policy

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[10] The Swiss GO consumer mix represents the mix of GOs sold to end consumers (full declaration). The Swiss GO supply mix represents the difference of GOs sold to end consumers minus GOs sold with dedicated electricity products based on renewable energies. Both mixes contain a share of few percents of untracked consumption (modelled with the residual mix).

scenarios. The additional electricity is expected to be produced in gas fired gas combined cycle power plants.

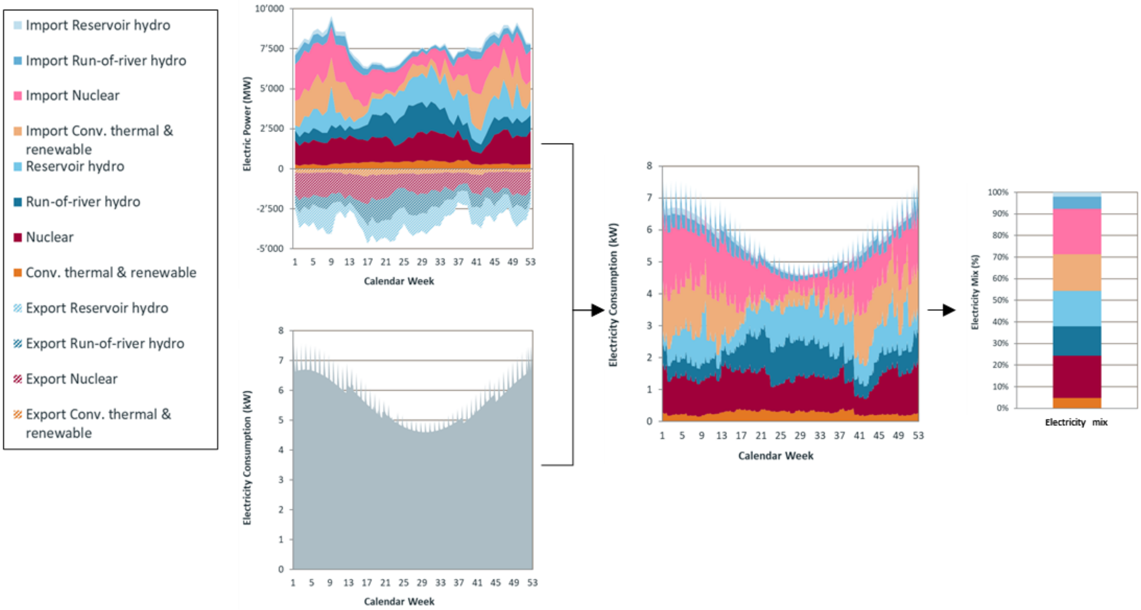

Figure 6: Derivation of the annual attributional electricity mix for buildings (and Switzerland). The electricity generation, export and import profile (top left) and the consumption profile of the building (and Switzerland, respectively; bottom left) are combined (centre) and integrated over time (right) in order to obtain the attributional electricity mix supplied to the building (and to Switzerland, respectively).

Material manufacture and construction of the buildings was modelled with the Swiss supply mix 2011 as published in the KBOB recommendation 2009/1:2016.

Results:

The results of the LCA of the residential building are described here as they are considered representative for both buildings assessed. The greenhouse gas emissions of the residential building Rautistrasse operated with the different electricity mixes vary between 9.8 and 12.4 kg CO_2-eq per m^2 and year (with 20.3 kg CO_2-eq per m^2 and year applying the longterm marginal electricity mix, see Figure 7). The variation is uniquely caused by differences in the amount of electricity supplied from the grid, the manufacturing of PV and battery systems for self generation and consumption of electricity and the greenhouse gas emission intensity of the electricity mix used in operation. The greenhouse gas emissions of material manufacture and construction (labelled “building” in Figure 7) are identical.

In most cases the share of greenhouse gas emissions caused during construction (and the corresponding end of life) is higher than the share of operational greenhouse gas emissions. More than two third of the greenhouse gas emissions caused during the life cycle of the residential building are due to construction and in particular building material manufacture.

The greenhouse gas emissions of the operation phase differ substantially, in particular when comparing for instance the environmental impacts of the attributional mixes established in this project with the mixes based on guarantees of origin, the average future electricity mix, the long term marginal mix and the ewz mix 2017.

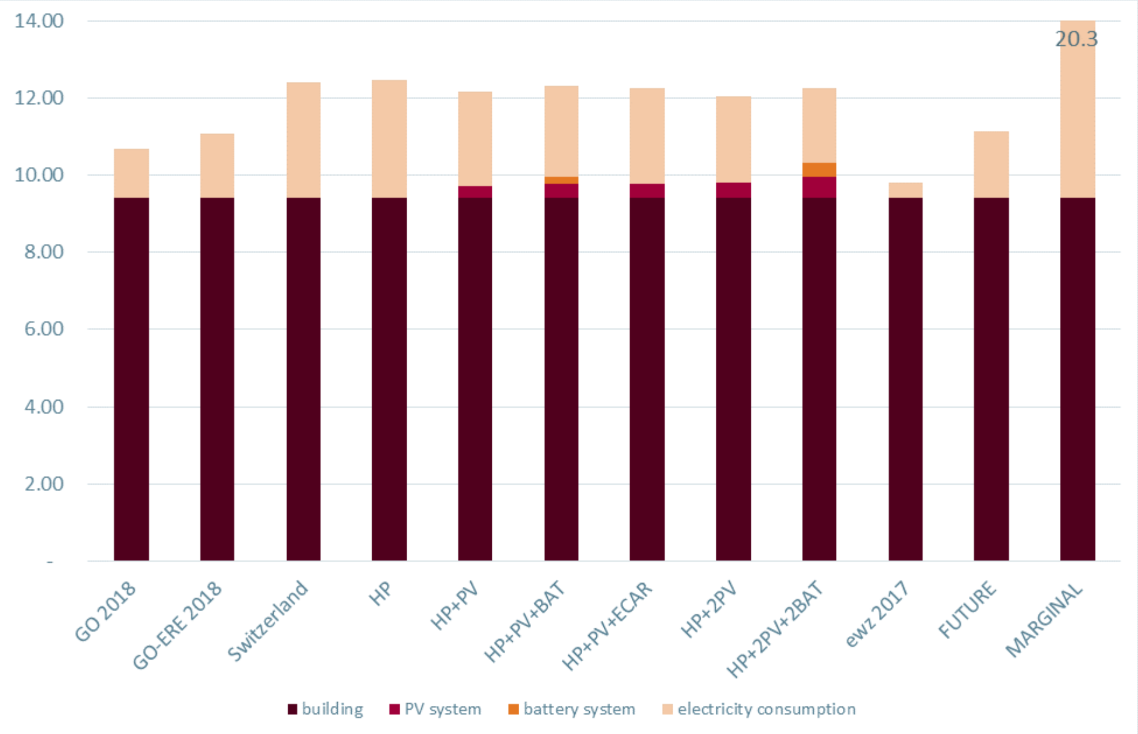

Figure 7: Greenhouse gas emissions in kg CO_2-eq. per m^2a of the residential building Rautistrasse, Zurich. Target values SIA 2040:2017: 9 and 3 kg CO_2-eq./m^2a (construction including end of life and operation, respectively).
GO 2018: Swiss consumer mix based to guarantees of origin 2018; GO-ERE 2018: Swiss supply mix based to guarantees of origin 2018, i.e. excluding deliberately purchased electricity products based on renewable energies; Switzerland: Swiss annual mix (national load profile); ewz 2017: ewz electricity mix based to guarantees of origin 2017; FUTURE: average future electricity mix Switzerland 2020-2050 according to the New Energy Policy Scenario of the Swiss energy strategy 2050; MARGINAL: long term marginal electricity mix (Switzerland and ewz).
Building specific electricity mixes matching hourly production and trade with the electricity consumption profile of the building, equipped with:
HP: heat pump for space heating and hot water; HP+PV: incl. 32 kWp PV system; HP+PV+BAT: including 32 kWp PV system and 32 kWh battery system; HP+PV+ECAR: including 32 kWp PV system and 7 electric car charging stations; HP+2PV: incl. 64 kWp PV system; HP+2PV+2BAT: incl. 64 kWp PV system and 64 kWh battery system;

The greenhouse gas emissions of the building specific electricity mix (“HP”) and of the national average attributional mix (“Switzerland”) are nearly identical. Self generated electricity leads to lower environmental footprints. The reduction in environmental impacts is mainly due to the lower demand of grid electricity. The environmental profile of grid electricity supplied to the building is hardly affected by the self generated and consumed PV electricity. The investment in storage facilities does not necessarily lower the greenhouse gas emissions of the building.

The results of the LCA of the office building show similar patterns: the environmental impacts of the building are very similar when applying the building specific and the Swiss average attributional electricity mix and lower when applying the Swiss and the ewz mix based on guarantees of origin.
The environmental impacts of the summer electricity mixes (building specific and Swiss average) differ substantially from those of the winter mixes. The winter mixes cause for instance between 160 and 169 g CO_2-eq/kWh and the summer mixes between 70 and 78 g CO_2-eq/kWh.

Discussion and conclusions:
The results of this study confirm the environmental relevance of electricity consumption of buildings and of the choice of the appropriate electricity mix model, irrespective of the environmental indicator chosen.

However, at the same time the results show that construction (manufacture of building materials, building elements and building technology) contributes between somewhat less than 50 % and more than 95 % to the life cycle based environmental impacts of buildings and therefore necessarily needs to be included in environmental analyses of buildings and the corresponding target values.[11]

The summer and winter Swiss electricity mixes show distinctly different patterns. During the summer period, more electricity is being produced with hydropower and the mix relies much less on imports of non renewable electricity from neighbouring countries. During the winter period substantial shares of fossil based electricity is being imported.

The annual and seasonal electricity mixes derived from the load profile of the two buildings and of Switzerland are close to identical. Obviously the load profile of energy efficient residential and office buildings are very similar to the load profile of the country.

The comparison of the Swiss national electricity mix 2018 established by integrating the combination of hourly technology mixes (domestic production minus commercial exports plus commercial imports) with the hourly load profile of Switzerland with the Swiss consumer mix based on guarantees of origin (GO) 2018 reveal substantial discrepancies: while Switzerland still consumes electricity with a share of 40 % nuclear power and 10 % fossil power, the GO mix shows shares of about 20 % and 4 % of nuclear and fossil power, respectively.

The average future Swiss electricity mix causes less environmental impacts than the Swiss annual attributional electricity mix. The level of environmental impacts is similar to the Swiss consumer mix based on guarantees of origin 2018. The average future mix lacks trade related technology shares and thus is hardly comparable with the other mixes which represent the current situation.

The ewz 2017 electricity mix shows the lowest specific environmental impacts due to the low share of nuclear power and the absence of fossil based electricity. This is however not a carte blanche for an excessive and inefficient use of electricity. Capacity constraints (in the case of ewz but also on country level) would call for additional power plant capacities, which, according to the national energy strategy 2050 and ewz scenarios, would likely be natural gas fired gas combined cycle power plants.

Despite the large variety in electricity mixes developed and analysed in this study, its variability can effectively be narrowed down by assigning specific electricity mixes to specific policy relevant questions and scopes.

Recommendations:

The analyses and results presented in this study lead to the following recommendations:

5. Refrain from establishing building sector specific electricity mixes and instead use Swiss national electricity mixes based on physical production and commercial trade as established in this project.
6. Reconsider the current use of the Swiss supply mix based on guarantees of origin in building LCAs and in LCAs in general. It is recommended to use the Swiss national electricity mix based on physical production and commercial trade, which reflects the economic reality of the purchase of electricity *production* (which is considered more important that the economic reality of the purchase of the *quality* of the electricity).

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[11] A recent study showed that building material manufacturers may lower the specific greenhouse gas emissions of their products by 65% on average (Alig et al. 2020), by investing in completely new technologies (hydrogen based steel) and in technical reduction measures such as carbon capture and storage (e.g. in cement production) in addition to switching to renewable energy sources.

7. Use the long term marginal electricity mix in scenario analyses of investments in new buildings and in particular in refurbishment projects with comparatively low energy efficiency. This is particularly important in situations where the electricity causes low specific environmental impacts and greenhouse gas emissions and shows the resilience of the investment towards changes in the electricity producing technologies.
8. Self generation of electricity with PV helps to reduce the environmental impacts of buildings supplied with a building specific or a national average electricity mix. The effect of on site individual storage of electricity in batteries is less distinct and thus not recommended. Centralised storage facilities on district level may show a different performance.

Given the increasing significance of the construction phase of buildings as shown in the building case studies, establish binding and steadily lowering target values on greenhouse gas emissions per m^2 and year. The SIA 2040 technical bulletin is a reality proven basis for such a regulation.

3.3.5 Sweden

The integration of a full LCA in building design or in architectural competitions is currently very limited in Sweden. If comparisons are carried out, they are usually based on the criteria from certification schemes mentioned in the previous section (Miljöbyggnad, LEED, BREEAM-SE or Nordic Swan Ecolabel). Common tools that can be used for this purpose include One Click LCA and Byggsektorns Miljöberäkningsverktyg (Building Sector Environmental Calculation Tool, a software tool with a built-in database, designed to easily calculate embodied greenhouse gas emissions in construction materials). Another method has been developed specifically for the consequential assessment of building energy solutions, called Tidstegen (Time Steps). It has been released as a free software tool[12], but has not been used in a lot of practical cases so far (Gode, Nilsson, Ottosson, & Sidvall, 2019).

3.4 Environmental Optimum between Construction/End-of-life and Operation

3.4.1 Denmark

There have been published research papers on subjects such as the environmental impact trade-offs between the heat produced to meet a building's space heating load and insulation produced to reduce its space heating load throughout the whole life-cycle of a building (Sohn et al. 2017).

3.4.2 France

At the moment, only the EQUER model[13] is linked with an optimization module (genetic algorithm[14]). Both annual average or hourly electricity mix are possible but of course the same option is used for all alternatives.

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[12] https://www.ivl.se/projektwebbar/tidstegen.html

[13] Recht T., Schalbart P., and Peuportier B., Ecodesign of a "plus energy" house using stochastic occupancy model, life cycle assessment and multi-objective optimisation, Hamza N and Underwood C. (Ed), Building Simulation & Optimization 2016, Newcastle, September 2016

[14] Genes correspond e.g. to insulation thickness, type and area of glazing etc. Individuals with highest performance are selected among a population, and their children are then selected again so that optimal solutions are identified after a certain number of generations, see details in the previous reference.

3.4.3 Hungary

In research, an optimization framework has been developed using a parametric approach and evolutionary algorithms. In this framework, currently and annual average electricity mix is applied, but the integration of hourly resolution and a future electricity mix is in progress.

3.4.4 Switzerland

As far as we know, this question has not been tackled yet in Switzerland. No specific methodology/approach is available for this question, but the technical bulleting SIA 2040 would be suited and used to address such a question.

3.4.5 Sweden

Recent LCA studies of Swedish buildings, in particular low-energy buildings, point to a rising importance of greenhouse gas emissions from construction materials compared to operational energy use (Larsson, Erlandsson, Malmqvist, & Kellner, 2016; Liljenström et al., 2015). This has lead to more focus on embodied emissions, and trade-offs between the impact of operational energy use and e.g. insulation materials are being discussed. However, there is currently no method or optimization framework to systematically find this optimum.

3.5 Synthesis

As a first step to prepare this synthesis, the modelling possibilities are summarized below with example choices in different tools and countries.

A) Electricity mix modeling possibilities

1. Generic or provider specific electricity mix
2. Regional, national or continental mix
3. Production mix or supply mix
4. Physical flows, contracts, guarantee of origin coupled with physical production, or guarantee of origin only, electricity trade with neighbouring countries
5. Mix corresponding to production + import, production – export + import (possibly according to guarantee of origin), or national electricity declaration
6. Universal electricity mix or use-specific electricity mix (heating, cooling, lighting, hot water…)
7. Present or future mix (e.g. average present-2050)
8. Average or marginal mix
9. Annual, seasonal or hourly mix
10. Allocation approach for electricity produced on site (photovoltaics, but also wind) exported to the grid

B) Synthesis table

Type of choice	Application cases			
	Regulation/ certification	Design tool	Facility assessment	Research
1_Generic vs provider-specific electricity mix	generic	generic	specific	
2_Geographic scope	national	national	national	
3_Production mix vs supply mix	supply mix	supply mix	supply mix	
4_Nature of trade flows	commercial or physical flows, explain the choice			
5_Modelling choice for the supply mix	production-export+import or production+import, explain the choice			
6_End uses dependence	universal if same temporal variation in buildings as national consumption, use-specific recommended otherwise (e.g. winter peak demand for heating)			
7_Time dimension	present, near future or long-term future mix, explain the choice			
8_LCA modelling approach	average, short-term marginal or long-term marginal, explain the choice			
9_Time granularity	annual or hourly, explain the choice			

Choices made in different existing tools

Criterion	Choices made in the different tools		
1 Generic or specific	Provider specific FR2[15]	Generic CH1, CH2, CH3, FR1, FR2, HU1, HU2, SE1, SE2	
2 Geographic scope	Continental	Regional SE2	National CH1, CH2, FR1, FR2, HU1, HU2, SE1
3 Type of mix	Production mix	Supply mix CH1,CH2, CH3, FR1, FR2, HU1, HU2, SE1, SE2	
4 Nature of trade flows	Physical flows CH2, FR1, FR2, HU1, HU2, SE1, SE2	Flows based on contracts CH3	Flows based on Guarantee of Origin (GO) CH1
5 Modelling choice for the supply mix	(1) Production + imports CH2, HU2	(2) Production – exports + imports FR1, FR2, HU1, SE1, SE2, CH3	(3) According to national electricity declaration CH1
6 End uses dependence (heating, lighting, cooling, etc.)	Universal mix CH1,CH2, CH3, FR2, HU1, HU2, SE1, SE2	Use specific mix FR1	
7 Time dimension	Present mix CH1,CH2, CH3, HU1, HU2, SE1	Near future mix FR1, FR2	Long term future mix CH3, FR2, HU2, SE1, SE2
8 LCA modelling approach	Average mix CH1,CH2, CH3, HU1, HU2, SE1	Marginal mix CH3, FR1, FR2, SE2	
9 Time granularity	Annual average mix CH1,CH2, CH3, FR1, HU1, HU2, SE1	Seasonally differentiated mix CH3, SE2	Hourly differentiated mix CH3, FR2, HU2
10 Allocation of in site PV electricity production	Impacts of self consumed part only (A2) CH2	Gross impacts minus PV impacts of fed in electricity (A1) CH1, CH3	Gross impacts minus grid mix impacts of fed in electricity (B) FR1, FR2, HU1, HU2, SE1, SE2

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[15] If the purpose of the study is to compare different electricity providers or contracts during operation

4. Suggested Solutions and Typologies

4.1 Introduction

This document was written for method and tool developers and policy makers (regulation). Users are invited to follow the recommendations provided by the developers (e.g. certification scheme, design tools).

Some of the following recommendations are case specific. We propose to distinguish the following four cases:
A. Assessments against benchmarks defined by voluntary certification schemes and regulation
B. Environmental reporting of facility management companies and assessment of private lifestyles:
C. LCA in building design tools (building optimisation independent of voluntary schemes or regulation)
D. LCA in building research

If appropriate these cases are listed in the recommendations related to 10 topics.

These recommendations address electricity related impacts. Methodological choices should be consistent across energy sources. Thus, the following recommendations should be applied on fuels as well. For instance, if a future renewable scenario is applied for electricity production, the same level of ambition should preferably be applied for gas (future supply with biogas and/or synthetic gases produced with biogenic carbon and renewable electricity) and liquid fuels.

4.2 Recommendations

1. Generic or provider specific electricity mix

Assessments against benchmarks defined by voluntary certification schemes and regulation:
A generic mix is commonly appropriate because e.g. in the design phase the occupant is generally not known and neither the electricity provider so that a specific mix cannot be identified. But if the occupant is known (e.g. in case of a household or a company developing a project for their own use) or if a long term contract exists with an energy provider, one of the Swiss methods (2000 W society) considers the specific mix of this provider but only for 50% of the total consumption in order to account for the risk that this situation may change.

Environmental reporting of facility management companies and assessment of private lifestyles:

If the goal of the LCA study is to compare various electricity providers in order to advise a facility manager or owner of an existing building, using a specific mix is more appropriate.

2. Regional, national or continental mix

Using a national mix is recommended, because the choice of some production technologies (energy transition towards renewables) is related to a national democratic process. Averaging a continental mix would lead to consider e.g. a % of nuclear or coal power plants even in countries having decided to abandon such technologies. But the national mix shall include imported electricity, see the following §4 and 5.

3. Production mix, supply mix

The supply mix should be used, as it corresponds to the electricity delivered to a country's consumers, including buildings.

4. Physical flows, contracts, guarantee of origin coupled with physical production, or guarantee of origin only, electricity trade with neighbouring countries

Using guarantees of origin (GOs) purchased independently of purchasing the electricity is not recommended because fossil or nuclear production may be artificially transformed into renewable electricity (a company could use electricity produced with coal or nuclear power but purchase GOs of renewable electricity to claim that it uses renewable power). It is likely to lead to double counting of renewable electricity (building LCAs in Switzerland and Norway both claim (partly) GOs of Norwegian hydroelectric power) because GOs are a voluntary means of communication.

Tool, certification scheme and method developers may either use “commercial flows” or “physical flows” to model electricity trade, and provide reasons for the choice.

It is recommended to consider physical domestic production (e.g. according to the data from transmission system operators) and commercial or physical trade with neighbouring countries reported on a transparency platform such as ENTSO-E in Europe (see the implication in §5).

Reasoning for commercial trade 1: Life cycle assessment is a method that complements economic information about products, services and technologies with information on their environmental impacts. That is why life cycle inventory models are supposed to describe or at least approximate economic realities. Data on commercial trade is chosen (and preferred to physical exchanges) because it better reflects the economic realities of electricity trade.

Reasoning for physical trade 2: The physical trade approach models the real exchanges and underlines an overall stability of the electricity supply at every time step which is part of the analysed service for the electricity consumption mixes. The “physical flow” approach can be used if the goal is to optimize the global energy balance of production/consumption in a country. It is also relevant to be used for analysing demand-side management strategies using hourly data to check if the consumption occurs during the best period of time in terms of GHG emissions).

The 2019 suggested update of the European Product Environmental Footprint method[16] proposes to select in priority supplier specific electricity product based on GOs, which has been discussed in §1, and otherwise a "residual grid mix" defined as characterizing the unclaimed, untracked or publicly shared electricity. As reasoned above we do not recommend methods based on GOs.

LCA in building research: compare physical and commercial trade to check whether or not differences are substantial.

5. Mix corresponding to production + import, production – export + import (possibly according to guarantee of origin), national electricity declaration

Tool, certification scheme and method developers may either use "production – export + import" or "production + import", and provide reasons for the choice.

Note: the reasoning presented below allows to inform the users of the "philosophy" behind each modeling approach even if there is no "right" and "wrong" modelling approach. The user should only select the one that better describe his context of use.

Reasoning for P-E+I: It is rare for a country to import electricity in order to export it further to another country, in particular in larger countries such as Germany, France or Poland. There are some transit contracts, which however are not part of the commercial trade data in the ENTSO-E transparency platform. Hence, it is safe to assume that all exported electricity stems from domestic production. It is also generally more precise because the % of import is related to the national consumption volume.
Reasoning for P+I: The exported electricity from the assessed country is considered equivalent to the electricity supplied to domestic customers. In addition, the P+I model is able to attribute the environmental responsibility of consuming the electricity in the assessed country not only to the direct "first level[17]" neighbouring countries but also to the "second level" countries (in a view of ensuring at every hour grid stability) even if there are no direct economical trade flows from the assessed countries and the second level countries contributing to the LCA of the consumption mix of the assessed country.

In both approaches, it is important to check that imports and exports do not include transit flows because this may lead to a bias if a large amount of imported electricity is not consumed in the country but readily re-exported. If the transit flows can be identified, they may be subtracted from both export and import.

A gross balance should be used because import and export electricity mixes are generally different so that import and export flows do not compensate (even if the physical flow is zero, see §4).

6. Universal electricity mix or use-specific electricity mix (heating, cooling, lighting, hot water…)

A universal mix is recommended if the seasonal variation of the electricity consumption in buildings is similar to the seasonal variation of national consumption. Use-specific average electricity mixes may be used otherwise (e.g. accounting for winter peak demand mix for heating).
We recommend to validate the universal and use-specific electricity mixes by comparing the LCA results to an hourly electricity mix model, for a sample of building types (residential, offices…), and their electricity demand for space heating, hot water, ventilation, lighting and auxiliaries.

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[16] Zampori, L. And Pant, R., Suggestions for updating the Product Environmental Footprint (PEF) method, EUR 29682 EN, Publications office of the European Union, Luxembourg, 2019, ISBN 978-92-76-000654-1, doi:10.2760/424643, JRC 115959

[17] For instance of a country A exports to a country B exporting to a country C, country B is first level and country A is second level for country C

7. Present or future mix (e.g. average present-2050)

The choice of the appropriate mix should be made considering the (un)certainty of the information, the appropriateness of the electricity mix in a 50 to 60 years framework of building operation and whether or not temporal variations matter or should be taken into account.

According to the goal:

Assessments against benchmarks defined by voluntary certification schemes and regulation: We recommend using a recent past mix, near future mix (e.g. 5 years) or a realistic long-term future mix and update it e.g. every 5 years in order to account for the real progress of energy transition while reducing the risk of under- or over estimating future impacts if the actual development is not on track compared to the scenario assumed.
Electricity mix data from TSOs, utilities, ministries or administrations (e.g. energy or environment agencies) and national statistics are normally available for the past years, near future and long term future.

LCA in building design tools and research: long term future mixes may be useful, particularly in sensitivity studies. In this case, scenarios (e.g. Eurostat, the EU Roadmap 2050, national energy strategies), statistical models or economical models (e.g. TIMES) can be used.
In any case the benchmarks against which the environmental impacts of a building are compared need to be aligned with the electricity mix applied (present, near future or future).
Electricity mixes (present, near future or future) with low environmental impacts may support buildings with low efficiencies and high specific electricity consumption. Perform sensitivity analyses with additional electricity mixes, for example long-term marginal electricity mixes (see Clause 8).

8. Average or marginal mix

Tool, certification scheme and method developers may either use average (attributional LCA) or marginal (consequential LCA), and provide reasons for the choice.

Reasoning for attributional mix: Buildings are just one (admittedly important) group of electricity consumers among many. The evolution of the electricity demand of buildings is the result of a mixture of efficiency gains in existing buildings, additional demand by new buildings on greenfields, change in demand by new buildings replacing old ones. It is hard to substantiate and to determine why new and refurbished buildings should be linked to additional power production and not to the average electricity production volume. An attributional mix treats all electricity consumers equally.

Reasoning for long-term marginal mix: Future scenarios of electricity demand and production are based on assumptions about the energy efficiency of buildings, cars, industrial processes etc. Existing buildings may reduce their operational environmental impacts by switching to electric heat pumps operated with renewable energies without improving the energy efficiency. Such refurbished old buildings may contribute to a demand for electricity which exceeds the production capacity of the ambitious future senario. In such situations longterm marginal mixes, established as the difference of

the future electricity mixes in a business-as-usual and in an ambitious energy scenario, are useful to test the resilience of refurbishment measures to the electricity mix in scenario analyses.
Reasoning for short term marginal mix

Replacing gas or fuel boilers by electric heating or heat pumps is often proposed to reduce GHG emissions. But this will create a high peak demand during cold winter days. This supplementary demand requires peak production techniques which may be different from average production because such capacities will be used only a limited time of the year. High CAPEX techniques would not be economical, so that older or cheaper capacities (e.g. gas or coal thermal plants) may be used.

In such a case a short term marginal mix is appropriate. Identifying a marginal mix is based upon an assumption (e.g. 10% top of the merit order) or requires a model of the electric system in order to identify which production process is added when adding a supplementary demand corresponding to the studied building consumption or energy use. This approach can be applied to a present situation, or a future prospective scenario, e.g. using a market allocation model (e.g. TIMES), i.e. a bottom-up linear optimization model that computes a least cost pathway for a system of interest subject to the satisfaction of specified service demands and user specified constraints.

Results can be averaged according to a typical load profile corresponding to a certain use (e.g. space heating, domestic hot water...) allowing simpler annual calculation to be performed in e.g. a regulation or certification scheme (e.g. in the French E+C- method 210 g CO_2/kWh heating, 83 g CO_2/kWh domestic hot water).

Studying the environmental benefit of smart buildings is an example research topic for which a consequential approach considering both short term and long term aspects is relevant. Buildings consume a large share of the total electricity production in many countries, so that accounting for interaction between this sector and the electric system is useful towards a higher global environmental performance.

9. Annual, seasonal or hourly mix

Tool, certification scheme and method developers may either use annual or hourly, and provide reasons for the choice.

Reasoning for annual mix:
electricity products and hence the technology shares purchased are usually bought on an annual basis. The use profiles of residential and office buildings do not significantly deviate from the national use profile, which reduces the need for hourly mixes. Many design tools are not able to model operational electricity demand nor supply on an hourly basis. Long term future electricity mixes presented in official future scenarios are annual, sometimes additionally seasonal but not hourly.

Reasoning for hourly mix:
The electricity demand varies according to the hour of the day (it is lower at night), the day of the week (it is lower during week-ends) and the season (it is higher during hot days due to cooling, and during cold days if electric heating is used). Thermal mass allows storing heat which may reduce the demand during peak hours and the related environmental impacts, but impacts are produced for the fabrication of such materials. Hourly calculation allows a trade off, which is useful in a design tool and does not add complexity for users if energy calculation is also performed hourly.

Results of an hourly calculation can be averaged over a year so that a simpler annual calculation can be performed in a regulation or certification method, accounting for a typical hourly profile corresponding to specific uses like heating, cooling etc.
Developing control systems algorithms or demand side management in terms of environmental impacts, i.e. in order to use the electricity when its carbon footprint will be lower and/or minimized, is an example research question where hourly calculation is appropriate.

10. Allocation approach for electricity produced on site (photovoltaics, but also wind) exported to the grid

Three main approaches are:

"Step[18] A" approach according to ISO 52'000-1, clause 9.6.6 (identical to approach B of the draft version of the revised EN 15978 standard): A share of the environmental impacts of on-site electricity production corresponding to the proportion of self-consumed electricity is accounted for in the building LCA. The rest of the impacts, corresponding to exported electricity, is accounted for in the electricity mix of the buyer of the electricity.

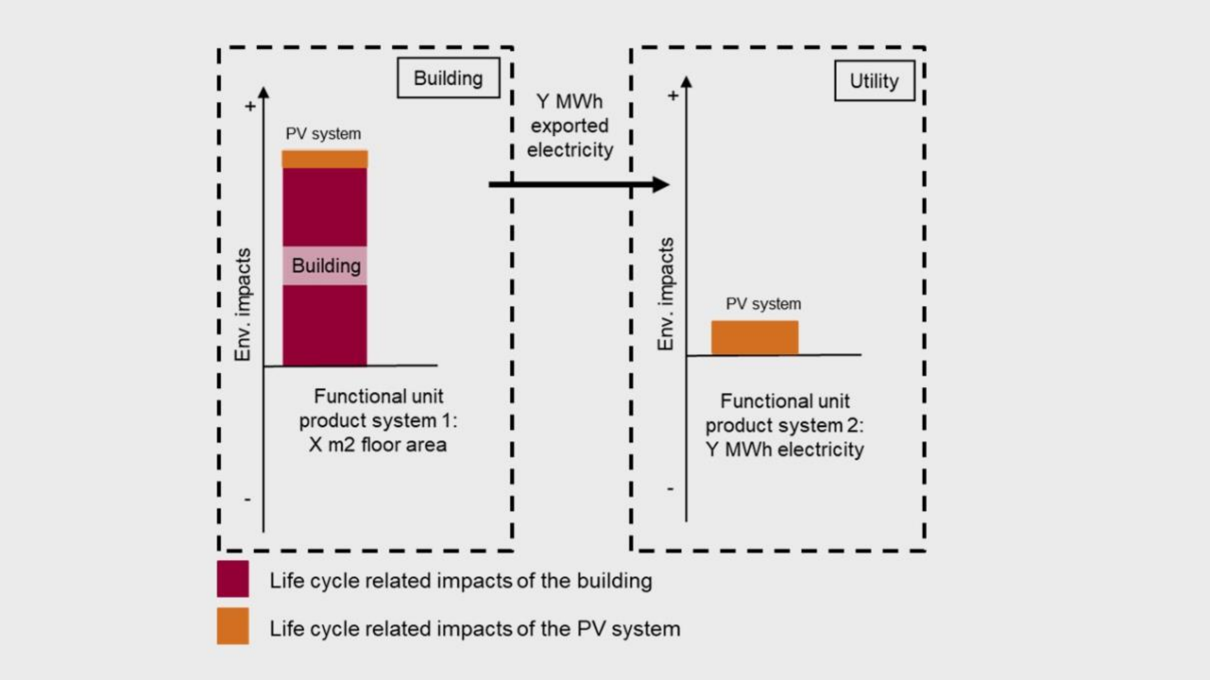

Figure 8: Step A (ISO 52000-1; and approach B of draft EN 15978): Allocation of environmental impacts caused by onsite energy production between the building and the energy ex-ported based on the share of self-consumed energy produced onsite. Note: The main elements of this approach are: (a) impacts related to the self-consumed share of PV electricity attributed to building; (b) impacts related to the ex-ported share of PV electricity attributed to exported electricity; (c) Overall sum of environmental impacts equals the observed environmental impacts.

"Step B" approach according to ISO 52'000-1, clause 9.6.6: All impacts of the PV system are allocated to the building. The building LCA also includes the potentially avoided impacts from exporting electricity to the national grid (or e.g. future European mix). In the grid mix of the one purchasing the exported

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[18] The word « step » in the standard is the label for an approach and actually corresponds to a methodological choice.

electricity, the exported electricity bears the environmental impacts of the national grid (or future European mix).

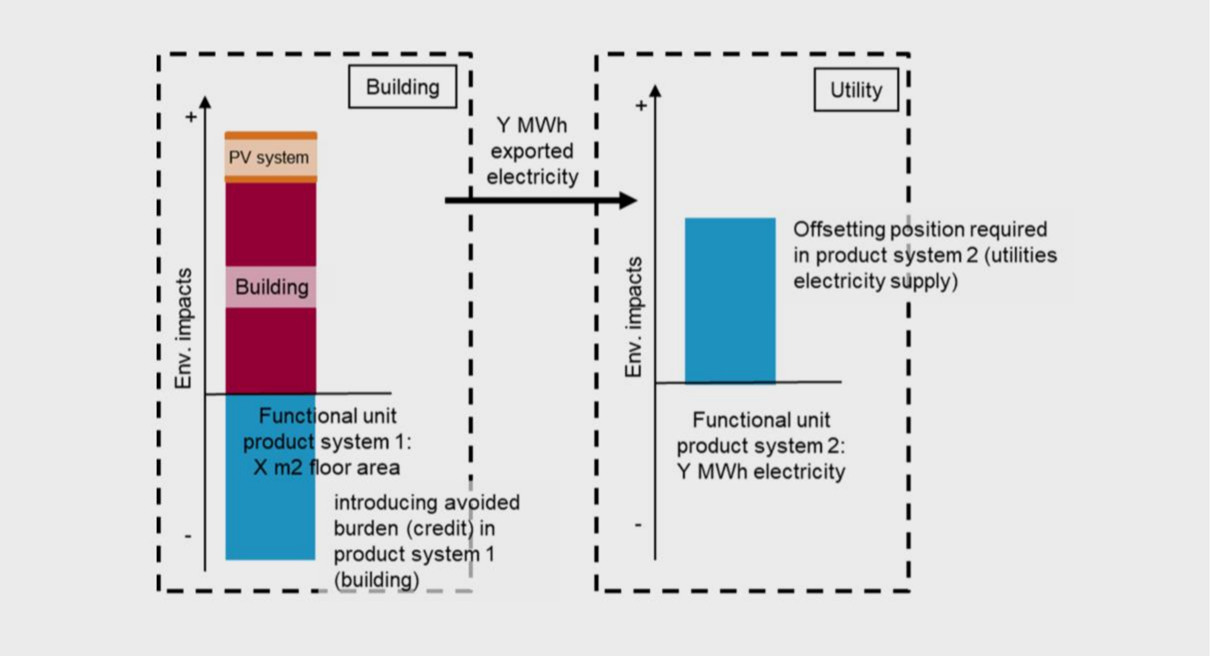

Figure 2: Step B (ISO 52000-1): Allocation of 100 % of the environmental impacts of onsite energy production and 100 % of potentially avoided emissions outside the system boundary to the building. Note: The main elements of this approach are: (a) Potentially avoided burdens (credits), determined with grid mix environmental impacts and amount of electricity exported, are accounted for in building LCA; (b) (equivalent) off-setting position in utility's LCA of electricity required to avoid dou-ble counting; (c) Overall sum of environmental impacts equals the observed environmental impacts, only if off-setting position is booked in utility's LCA.

Approach A of EN 15978 standard: All impacts of the PV system are allocated to the building, and potentially avoided impacts from electricity export are reported as additional information in module D, which is outside of the building LCA boundaries and therefore not accounted for in the building LCA result contrarily to step B of the ISO standard.

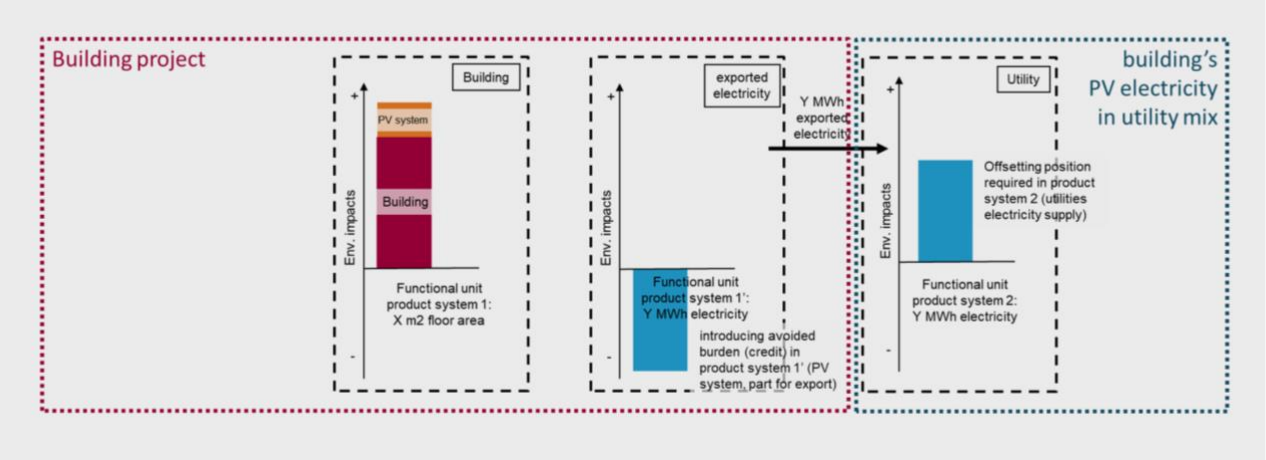

Figure 4.3: Approach A of EN 15978 standard: Allocation of 100 % of the environmental impacts of onsite energy production and 100 % of potentially avoided emissions in Module D2, outside the system boundary of the building but as part of the building project.

In step B of the ISO standard and approach A of the CEN standard, the avoided impacts have to be evaluated according to an electricity mix which can either correspond to attributional LCA (average mix) or consequential LCA (marginal mix), using hourly, seasonal or annual time step, recent past or future mix etc. (see the previous §). It is recommended to be consistent in evaluating the impacts related to the electricity consumption from the grid and potentially avoided impacts from PV export, and to report potentially avoided impacts separately as additional information.

Reasoning for the Step A approach of the ISO standard (and Approach B of the current draft of EN 15978):

Step A approach ensures that electricity produced on-site and exported to the grid shows the environmental performance of the technology used to produce it (e.g. PV, wind, combined heat and power plant). The share of environmental impacts of manufacturing, operating and dismantling the energy producing technology attributed to the building corresponds to the share of self-consumption. Building integrated PV systems may be subdivided into the parts needed for weather protection (front glass, supporting structure; attributed to the building's LCA) and the parts needed to produce electricity (panel except front glass, cabling, inverter; attributed to electricity production). The building's environmental performance depends on the share of self-consumption.

Step A may be implemented in two different ways: In option A1 100 % of the construction and manufacturing efforts of the energy technology (such as (BI)PV) are attributed to the building in Module A and the pro rata environmental impacts of exported energy are subtracted in Module B6. In option A2 the share of self-consumption is determined and only this share of construction and manufacturing efforts of the energy technology is attributed to the building in Module A. No further (negative) environmental impacts shall nor need to be accounted for in Module B6, see Table 1: Example application of step A approach.

This approach ensures that the environmental impacts of renewable energy are only accounted once: the self-consumed part is attributed to the building's LCA; the exported part is attributed to the utility or third party purchasing the renewable electricity. No potentially avoided impacts (grid mix electricity) are accounted for in the building's LCA which would imply that the exported electricity must bear the environmental impacts of the grid mix (corresponding to the avoided impacts).

How the environmental impacts of a building with and a building without (BI)PV[19] compare shall be assessed by comparing the LCA of a building with and a building without (BI)PV and not by including avoided burdens into the assessment of the building with (BI)PV.

Reasoning for the Step B approach of the ISO standard:

A building exporting locally produced renewable electricity corresponds to a system with two co-products: the building and an electricity production. Evaluating the part of impacts related to the building is an allocation problem. The environmental benefit of a renewable production compared to the standard grid (avoided impacts) can be allocated to the consumer or to the producer. Installing a PV roof requires more effort (investment, time) than just consuming renewable energy produced by others. The whole roof is part of the property, and not only the self-consumption % of the PV roof. This is why method B accounts for this benefit in the environmental value of the property. Also, this benefit is a consequence of a design decision, so that it is accounted for when comparing a building with and without PV. There is no double counting of this benefit because if the exported renewable electricity is included in the grid mix, the benefit of the local renewable production is lower. The LCA results remain consistent if the scale of the evaluation is expanded at the neighbourhood level: neighbour buildings may consume exported electricity so that the self-consumption % is larger than modelling each building separately, but the environmental impact of a building remains the same using method B. The results are also consistent regarding the environmental payback time of e.g. PV modules.

Reasoning for the approach A of the draft CEN standard:

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[19] Building Integrated PV

The reason for attributing all the impacts of the renewable energy producing unit to the building is the same as for the step B approach from ISO. Namely, that the unit is part of the building (site). It is a conscious choice of the building owner/designer to place the energy producing unit (sometimes for economic reasons), so he or she should know which impact this generates.

Reporting the potential benefits from exported energy in module D (outside of the system boundaries) is consistent with the recycled content approach at material level (prescribed by ISO 21930 and EN 15804). In both cases potential benefits occurring outside of the system boundaries are reported separately, as additional information and shall not be summed up with modules A-C results. This prevents uncertain benefits (e.g. the choice of the grid mix used to model the avoided impact from exported electricity is prone to discussion and likely to evolve over the life cycle of the building) from being credited against impacts that occur today (production of the energy producing unit) and from being accounted twice (in the building LCA and in the LCA of the grid mix of the utility purchasing the exported electricity).

Table 1: Example application of step A approach

			Module [A]	Module [B]			Module [C] assuming 5% of [A1-A5] embodied impacts for end-of-life	Module [D]		Issues/Comments
			[A1-A5] Assumptions: Building embodied impacts: 100,000 kgCO2e PV embodied impacts: 15,000 kgCO2e	**[B2]** Assumptions: 10% of [A1-A5] embodied impacts for maintenance	**[B4]** Assuming 1 replacement over the building's life cycle	**[B6]** Assumptions: Building operational energy use over life cycle: 500,000 kWh Total energy generated by the building over life cycle: 160,000 kWh Self-consumed energy: 40,000 (25% of total energy generated by the building) Exported energy: 120,000 kWh (75% of total energy generated by the building)		**[D1]** Materials reuse, recycling and recovery	**[D2]** Exported energy	
Approach B --- **Building LCA to report:** impacts from **building and self consumption PART of the energy generating equipment.** **1 additional table presenting the impacts of exported energy - NOT part of the building assessment -** as presented hereby in yellow header proposed **for ALL 22 impacts/indicators**	**Building assessment** incl. Building + PV-part related to energy consumed by the building	***Flows*** *KWh*				***460'000 kWh***			**-**	Two complete results tables showing the impacts related to the intended use of the building (white header) and to the exported energy (yellow header) separately. The assessment of exported energy follows the rules of ISO 52000-1, clause 9.6.6.2
		Impacts kgCO2e	**103'750**	**10'375**	**108'938**	**138'000 kgCO2e**	**5'188 kgCO2e**		**-**	
	Energy sub-system made available to third parties as a service PV-part related to energy exported	*Flows* *kWh*				*-120'000 kWh*			*-120'000 KWh*	
		Impacts kgCO2e	11'250 kgCO2e	1'125 kgCO2e	11'813 kgCO2e		563 kgCO2e		**-36'000 kgCO2e**	

Additional table to describe energy flows - to be further developed and finalised in line with the updated main LCA results table for consistency and avoidance of duplication

Additional Table 3: Operational building energy use & generation (accompanying both versions of table 1 above)

	[B6]			
Energy reporting ***(Energy flows)***	**Building energy use**	**[B.6.1]** **Regulated building-integrated systems**	*350'000 KWh*	**Total Imported energy** *Total energy use - Generated energy used in the building*
		[B.6.2] **Non regulated building-integrated systems**	*100'000 KWh*	
		[B.6.3] **Non building-integrated systems**	*50'000 KWh*	
		Total energy use *Sum of [B.6.1] + [B.6.2] + [B.6.3]*	***500'000 KWh***	***460'000 KWh***
	Building energy generation	**Used in the building**	*40'000 KWh*	
		Exported	*120'000 KWh*	
		Total energy generated *Sum of Energy used in the building + Exported*	***160'000 KWh***	

4.3 Conclusion

Even if it is sometimes difficult to express recommendations that are relevant in all situations, this document explains the choices made in different contexts. The following Table 2: Synthesis tabl an overview of the recommendations, and Table 3 presents the choices made in different existing tools. To ensure transparency in LCA results, the assessment method of electricity related emissions must be described by indicating methodological choices listed in Table .

Table 2: Synthesis table

Type of choice	Application cases			
	Regulation/ certification	Design tool	Facility assessment	Research
1_Generic vs provider-specific electricity mix	generic	generic	specific	
2_Geographic scope	national	national	national	
3_Production mix vs supply mix	supply mix	supply mix	supply mix	
4_Nature of trade flows	commercial or physical flows, explain the choice			
5_Modelling choice for the supply mix	production-export+import or production+import, explain the choice			
6_End uses dependence	universal if same temporal variation in buildings as national consumption, use-specific recommended otherwise (e.g. winter peak demand for heating)			
7_Time dimension	present, near future or long-term future mix, explain the choice			
8_LCA modelling approach	average, short-term marginal or long-term marginal, explain the choice			
9_Time granularity	annual or hourly, explain the choice			

Table 3: Choices made in different existing tools

Criterion	**Choices made in the different tools**		
1 Generic or specific	Provider specific FR2[20]	Generic CH1, CH2, CH3, FR1, FR2, HU1, HU2, SE1, SE2	
2 Geographic scope	Continental	Regional SE2	National CH1, CH2, FR1, FR2, HU1, HU2, SE1
3 Type of mix	Production mix	Supply mix CH1,CH2, CH3, FR1, FR2, HU1, HU2, SE1, SE2	
4 Nature of trade flows	Physical flows CH2, FR1, FR2, HU1, HU2, SE1, SE2	Flows based on contracts CH3	Flows based on Guarantee of Origin (GO) CH1
5 Modelling choice for the supply mix	(1) Production + imports CH2, HU2	(2) Production – exports + imports FR1, FR2, HU1, SE1, SE2, CH3	(3) According to national electricity declaration CH1
6 End uses dependence (heating, lighting, cooling, etc.)	Universal mix CH1,CH2, CH3, FR2, HU1, HU2, SE1, SE2	Use specific mix FR1	
7 Time dimension	Present mix CH1,CH2, CH3, HU1, HU2, SE1	Near future mix FR1, FR2	Long term future mix CH3, FR2, HU2, SE1, SE2
8 LCA modelling approach	Average mix CH1,CH2, CH3, HU1, HU2, SE1	Marginal mix CH3, FR1, FR2, SE2	
9 Time granularity	Annual average mix CH1,CH2, CH3, FR1, HU1, HU2, SE1	Seasonally differentiated mix CH3, SE2	Hourly differentiated mix CH3, FR2, HU2
10 Allocation of in site PV electricity production	Impacts of self consumed part only (A2) CH2	Gross impacts minus PV impacts of fed in electricity (A1) CH1, CH3	Gross impacts minus grid mix impacts of fed in electricity (B) FR1, FR2, HU1, HU2, SE1, SE2

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[20] If the purpose of the study is to compare different electricity providers or contracts during operation

Table 4: Checklist for the documentation of building LCA results

Criterion	Choice made in the LCA method regarding the assessment of electricity related impacts
1 Generic or specific	Generic ☐ Provider specific ☐ Other ☐
2 Geographic scope	Continental ☐ National ☐ Regional ☐ Other ☐
3 Type of mix	Production mix ☐ Supply mix ☐ Other ☐
4 Nature of trade flows	Physical flows ☐ Flows based on contracts ☐ Flows based on Guarantee of Origin (GO) ☐ Other ☐
5 Modelling choice for the supply mix	Production + imports ☐ Production – exports + imports ☐ According to national electricity declaration ☐ Other ☐
6 End uses dependence (heating, lighting, cooling, etc.)	Universal mix ☐ Use specific mix ☐ Other ☐
7 Time dimension	Present mix ☐ Near future mix ☐ Long term future mix ☐ Other ☐
8 LCA modelling approach	Average mix ☐ Marginal mix ☐ Other ☐
9 Time granularity	Annual average mix ☐ Seasonally differentiated mix ☐ Hourly differentiated mix ☐ Other ☐
10 Allocation of in site PV electricity production	Impacts of self-consumed part only ☐ Gross impacts minus PV impacts of fed in electricity ☐ Gross impacts minus grid mix impacts of fed in electricity ☐

Annex A: Different Electricity mix models – a description

In this Annex A the different models used to derive life cycle inventories of electricity mixes, their assumptions and data sources are described.

A.1 Introduction and scope

The modelling of electricity mix is challenging as there are many options regarding the temporal and spatial scope (Esser & Sensfuss 2016).

The electricity network is highly interconnected, which makes the modelling of electricity challenging from a geographical scope. Usually a national scale is considered, but for traded electricity different modelling approaches are available (Itten et al. 2014; Ménard et al. 1998):

- Model 1: supply mix = domestic electricity production mix. This is the production of different power plants within a geographical boundary, without electricity trading considered. This can be an acceptable simplification in countries with a low share of import/export.
- Model 2: supply mix = domestic production + imports. This model does not differentiate between electricity exported and electricity supplied to the domestic market.
- Model 3: supply mix = domestic production – exports + imports. This model assumes that the exported electricity is produced by the domestic power plants and the imported electricity is used exclusively for electricity supply within the importing country. This model does not take into account that the imported electricity can be re-exported to other countries.
- Model 4: supply mix = domestic production + net imports/exports. This model assumes that simultaneous, physically measured imports and exports is transit trade. This may deviate from the economic realities.
- Model 5: consumer mix. The electricity mix of the domestic supply is modelled according to the integration of the electricity declarations of all electric utilities in a country. The declaration includes a differentiation according to technology and whether or not the electricity is produced domestically or abroad.

Besides the national scale, in some cases a regional or continental scale may also be applied.

The following sections present the options for modelling the temporal scope of electricity mix: present mix and future scenarios, as well as intra-annual variation between seasons and hours. Finally, modelling approaches for determining the longterm marginal electricity mix for a consequential LCA are described.

A.2 Present annual average electricity mix

The most common approach applied in LCA is a static approach when an average annual national mix is used for the entire reference study period. This average mix may be an electricity mix from a specific recent year or an average of a longer period.

In LCA studies of buildings, typically the supply mix of the country is applied, but there may be differences between countries in the consideration of import and export flows (see the different models in the previous section).

A.3 Future annual average electricity mix

Data for the future annual average electricity mix is based on several expected future data points. The forecasting can both include dynamic data related to the development within the mix and to the expected technological development.

This approach has been introduced in the national LCA tools for buildings in Denmark, where the forecasting scenario is based on estimation of the expected development of the energy mix for electricity and district heating. The forecasting scenario does not include forecasting technology development of boilers etc. The first dataset was published in 2016 (COWI, 2016) and updated in 2020 (COWI, 2020). The approach includes energy composition in five data points and the corresponding expected environmental impacts. The first version included forecasting from 2015-2050, while the updated version only covers 2020-2040. Table 4 gives an example of the values for one selected impact category (greenhouse gas (GHG) emissions).

Table 4: Life cycle based greenhouse gas emissions of electricity and district heat in g CO_2-eq/kWh and MJ, respectively for the forecasting scenarios for five data points (year) (COWI 2016, COWI 2020)

	2015	2020	2025	2030	2035	2040	2050
Electricity: 2015 g CO_2-equiv./kWh	352	201	169		31		24
Electricity: 2020 g CO_2-equiv./kWh		264	135	47	41	40	
District heating: 2015 g CO_2-equiv./MJ	52	31	28		20		16
District heating: 2020 g CO_2-equiv./MJ		37	24	20	19	19	

A.4 Seasonal (summer/winter) average electricity mix

A seasonal variation can be generally observed in the composition of the electricity mix, which has been shown by several researchers. The environmental impacts are typically lower in the summer months than in the winter months (Roux et al. 2016b). This seasonal variation can be explained by the variation on the supply side on the one hand, and the variation on the demand side on the other hand.

On the supply side, the output of renewable technologies exhibits high variability depending on weather conditions. For example, photovoltaic power plants produce more solar energy in summer than in winter and there is a larger production from run-of-river power plants in spring.

On the demand side, there is also some seasonality, for example space heating induces winter peak demand in countries with a high penetration of electric heating, while space cooling may result in summer peaks. Peak demand leads to an increase of production from fossil thermal plants, which can flexibly participate in load modulation.

A seasonal electricity mix has been developed in some countries, for example in Switzerland, as an average of winter months (October-March) for winter electricity mix and an average of summer months (April-September) for summer electricity mix (Frischknecht et al. 1996).

A.5 Hourly resolution of the electricity mix

Seasonal variation of the electricity demand, and therefore of the mix, may occur due to heating and cooling loads according to climatic conditions. Moreover photovoltaic electricity production, higher in summer, may cover the electricity consumption for heating, higher in winter, on an annual basis. However, the environmental impacts related to the electricity consumed during the heating season (winter) may differ substantially from the environmental impacts of PV electricity or, in case a “potentially avoided emissions” concept is applied, from the emissions of the electricity avoided by feeding PV electricity into the grid.

The variation can also occur according to the day of the week because of a lower consumption in office buildings during week-ends. Hourly variation corresponds to human activities: for instance the demand is currently lower late during nighttime. Hourly values of electricity production using different technologies are provided by Transmission System Operators (organizations managing the grid). The data includes imported quantities from different countries. Using some assumption regarding imported electricity (e.g. yearly average production mix corresponding to the exporting country etc.), the mix corresponding to consumed electricity is therefore estimated for past years.

Electric system models can be developed (e.g. Kiss et al. 2018; Roux et al. 2017) in order to evaluate hourly mix values according to energy transition scenarios and climatic data. Energy consumption in buildings is generally estimated using "typical meteorological years" (TMY), corresponding to a statistical average of e.g. 20 real years. The electricity supply mix corresponding to such TMY can be evaluated on an hourly basis using an electric system model. Energy transition scenarios may provide installed capacities in future years, and the corresponding hourly mix can also be evaluated using the same electric system model. Effects of climate change on e.g. hydroelectric power production can be taken into account.

A.6 Marginal electricity mix (electricity mix(es) applicable in consequential LCAs)

Introduction

A new construction increases the electricity demand, while renovating a building usually aims at reducing this demand. In attributional LCA, an average electricity mix is considered when evaluating the corresponding environmental impacts. In consequential LCA, a marginal mix may be considered instead, in order to account for the consequences of the studied system (building) on the background system (including electricity production).

Marginal electricity mixes depend on the time scale and may be defined on a short term for particular time during a day (e.g. peak loads during cold and hot days, respectively), or during a season (e.g. reduced electricity consumption during the winter season caused by the replacement of direct heating systems with heat pumps) and they may be defined on a long term to capture long term changes in electricity demand due to national energy policy measures (affecting both the demand and energy efficiency in housing, industry, mobility, etc.).

Furthermore, electricity mixes usable in consequential LCA may be based on 1) economic models, 2) policy scenarios quantifying the annual average (and seasonal) production of electricity, 3) a “thinking model”.

1) Marginal electricity mix based on techno-economic models

If the electricity demand is reduced thanks to retrofit measures in a building with electric heating, the most expensive electricity production may likely be avoided which does not necessarily correspond to average impacts. For instance, in France during the winter peak electricity demand, thermal power plant production will be avoided rather than cheaper production like hydro-power. In such case, the reduced greenhouse gases emissions correspond to these thermal plant emissions and not to average emissions. Marginal processes can also be considered when evaluating additional impacts related to an increase of consumption (new building), or when evaluating potentially avoided impacts corresponding to onsite renewable electricity production exported into the grid, if applying an avoided burden approach (see Chapter XXX on exported electricity).

The marginal technology is among the technologies on the market capable of responding to changes in demand (Mathiesen et al. 2009). Long term changes (e.g. large scale change leading to change infrastructure and installed capacities) or short term changes (leading to adapt the production without changing the infrastructure) could be considered.

Existing methods regarding the use of marginal electricity production in consequential LCA have been reviewed, eg in Menten et al. (2015). The short-term marginal mix depends on installed capacities, electricity market, resources and possible downtime or maintenance activities (Lund et al. 2010). Two terms are considered in the Greenhouse Gases Protocol (WBCSD & WRI 2007): one corresponds to modified infrastructure (long term) and one to modified production (short term). A building has a limited influence on the whole electric system and infrastructure, so that only the term corresponding to a change in production is generally considered when the aim of the LCA study is to help in the design of a single building (Roux et al. 2016a). But if LCA is used on a large scale, e.g. in the frame of a regulation, the whole building sector will be influenced so that long term effects have to be considered (Roux et al 2016a).

The different production techniques are ranked using a "merit order". Technologies that cannot be adjusted according to the demand (e.g. wind or PV, that depend on the weather) are at the bottom of this ranking. Adjustable technologies with the lowest constraints and the highest cost are at the top. The Greenhouse Gases Protocol suggests as default value a marginal mix corresponding to the 10% top ranked productions.

A more conceptual/theoretical way based upon physics is to evaluate the mix with and without the studied building, using a model representing the electric system as presented in the previous paragraph.

Like in the previous paragraph, a marginal electricity mix can be defined for past years (historical mix) or for a long term period using energy transition scenarios.

2) Marginal electricity mix based on policy scenarios

Countries like Switzerland established long term energy and electricity strategies to step out of nuclear power and engage in renewable energies. Usually these strategies include different scenarios of possible developments, including a business as usual scenario and scenarios of different ambition levels (Prognos 2012). The scenarios cover both supply and demand and include assumptions on the development of consumption, technology and shares of technologies. In the energy sector the energy efficiency of buildings, the portfolio of heating systems (e.g. share and volume of electric heat pumps installed), and the development of individual mobility (e.g. number of cars, average annual distances travelled) as well as the development and the shift in technologies (e.g. fuel efficiency, share of electric and hydrogen cars) are important aspects which determine the future demand in fuels and in electricity.

Assessing the environmental impacts of electricity consuming products such as buildings or private cars which do not meet the energy efficiency assumptions assumed in the more ambitious energy scenarios call for a longterm consequential electricity mix.

Such a consequential electricity mix is defined as the difference of the absolute production volumes in a given year in the future (e.g. 2050) in the business as usual scenario and in the new energy policy scenarios (see example in Annex B Switzerland). It indicates the production volumes per power plant technology which would be needed in case the energy efficiency targets are missed. And the energy efficiency targets are most likely missed with products (for instance buildings and private cars), which do not meet the individual energy efficiency requirements of the new energy policy scenarios.

3) Marginal electricity mix based on a thinking model for Europe

This approach applies the following thinking model: The amount of electricity based on renewable energies is limited. If electricity is used economically, utilities may be able to shut down (and dismantle) power plants which run on fossil or fissile fuels, i.e. lignite, hard coal, fuel oil, natural gas and nuclear power plants. Because this opportunity is available as from today, the use of the present (for instance European) non-renewable residual electricity mix is recommended (see example in Annex B, Switzerland).

A.7 Electricity mix based on information from guarantee of origin certificates

The current electricity market distinguishes between the physical electricity and the quality of the electricity (described by guarantees of origin), which are traded separately (see Figure 9). As a consequence, the certified quality of the electricity purchased and consumed by a country or a building may significantly deviate from the physical electricity mix purchased and consumed. This deviation occurs when the electricity qualities

(GOs) are purchased independently of the physical amounts, the latter being purchased on a spot market with no information about their provenience.

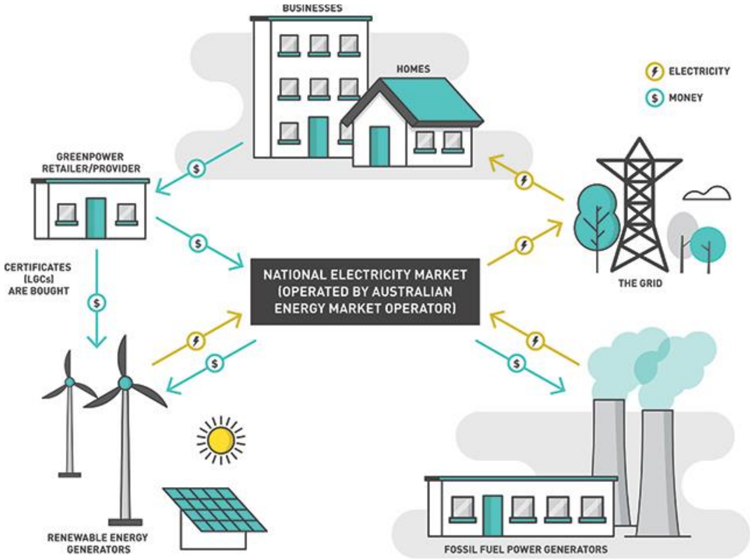

Figure 9: System of guarantees of origin and certificates explained in an Australian context; Source: https://www.choice.com.au

Electric utilities have to balance their guarantees of origin with the electricity supplied on a yearly basis. Temporal variations within days, weeks and seasons are not reported and thus disregarded in the electricity mix based on guarantees of origin. An electricity mix based on GOs is thus an attributional annual average electricity mix. In this report annual average electricity mixes based on GOs are listed and treated separately due to their particularities described above.

The Swiss supply mix used for instance in life cycle assessments of buildings according to the technical bulletin SIA 2040 SIA energy efficiency path (SIA 2017) is based on the accounting of GOs. The life cycle inventories of the Swiss supply mix in 2014 were compiled by Messmer and Frischknecht (2016) using the “Cockpit Stromkennzeichnung” published by Swissgrid (2016). This is an aggregation of the reported electricity certificates of all electric utilities in Switzerland. The Swiss supply mix contains a relevant share of non-verifiable electricity not covered by GOs.[21] The technological composition of non-verifiable electricity needs to be suitably approximated in the life cycle inventory. The European residual mixes published by the Association of Issuing Bodies (AIB 2015) account for the non-cancelled GOs in the European electricity market. This so-called European attribute mix (EAM) was used to model the share of non-verifiable electricity in the Swiss supply mix 2014 (Messmer & Frischknecht 2016).

The “Cockpit Stromkennzeichnung” does not distinguish whether or not the quality of electricity was purchased from the same source like the physical amount of electricity. Hence, the electricity mix based on the purchases of the physical amounts of electricity and its supply to Swiss consumers may differ from the one reported in the “Cockpit Stromkennzeichnung”. Several utilities, such as EKZ offer electricity products including significant shares of European hydroelectric power. It is likely that these utilities purchase power from e.g. Axpo with significant shares of nuclear power, and add GOs from Norwegian hydroelectric power plants to create electricity products which appear to be 100 % renewable.

The KBOB guidelines for life cycle assessment of building products (KBOB et al. 2015) include rules on how to deal with GOs. Companies which may choose their electricity supplier must purchase the physical amounts and the quality of electricity from the same power plants (congruency). Otherwise they shall establish the

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[21] The declaration of non-verifiable electricity on the electricity labelling is no more allowed since 1 January 2018 (UVEK 2017).

environmental profile of the mix of the physical electricity purchase and may report on the environmental benefits due to the purchase of GOs of renewable electricity as an improvement measure.

Norway is issuing Guarantees of Origin (GOs) for electricity. On average Norway is a net exporter of electricity, Norwegian power suppliers that do not purchase GOs for their sold electricity, must refer to NVEs (The Norwegian Energy Regulatory Authority) national electricity disclosure when communicating the production sources. NVEs base their calculations for the disclosure on the best practice recommendations from the European RE-DISS project (2020), and is based on European trade of GOs and the European Attribute Mix (EAM)/European residual mix for Norway, undertaken by Association of Issuing Bodies (AIB 2016, 2017, 2018 and 2019). Table 6 shows the relationship between Production, Exchange, Consumption and GOs in Norway for 2015 to 2018 (NVE 2016, 2017, 2018 and 2019).

Table 5: Disclosure of Norwegian electricety 2015 to 2018 (NVE 2016, 2017, 2018 and 2019).

Year	**Consumption (TWh)**	**Norwegian Production (TWh)**					**GO Norway (TWh)**		**EAM production (TWh)**				**Norwegian Production**	**Disclosure Norwegian Power**
		Hydro	Wind	Thermal Biofuel	Fossil Thermal	Total	GOs issued	Gos redeemed	Renewable Power	Nuclear Power	Fossil Thermal	EAM total	g CO2/kWh	g CO2/kWh
2015	130,4	139,0	2,5	0,2	3,1	145,0	134,7	19,4	3,9	34,2	59,6	97,7	17,0	509
2016	133,1	144,0	2,1	0,2	3,2	149,5	136,0	21,0	3,7	23,8	68,9	112,0	16,0	530
2017	134,1	143,0	2,1	0,2	3,2	149,3	109,0	25,0	7,6	29,4	59,2	108,7	16,4	531
2018	136,7	139,5	3,9	0,2	3,3	146,8	140,9	19,7	2,6	39,1	64,1	105,7	18,9	520

And here is the foundation for a controversy since Norwegians households pays for electricity based on the floating price on the European electricity market, and only 20% buys GOs. Due to the bottlenecks in the import/export to Norway, the Norwegian electricity prices is on average lower than the European prices. Thus, most Norwegians regard their electricity to be (mostly) hydropower with a very low carbon footprint, whereas the disclosure shows a significantly higher carbon footprint (a factor of 25!), because more than 85 % of the GOs are exported.

Annex B: National electricity mix models

B.1 Introduction and scope

This Annex is structured according to the list of mixes in Annex A and within each of the mixes according to countries/organisations. It describes the actual composition of the different mixes as applied/modelled in the different countries reporting.

B.2 Present annual average electricity mix

Denmark

The LCA data for Danish electricity supply and district heating for use in LCAbyg was developed by Cowi consulting in 2016 (COWI 2016). Table 6 shows the electricity mix for the dataset representing year 2015. Based on this data environmental impact categories are calculated.

Table 6: Electricity mix in percentages (%) in Danish electricity production for LCA dataset representing year 2015 (COWI 2016).

	Condense (steam turbine)		CHP (steam turbine)					Engine		Gas turbine	Industry + bio factories	Wind	PV
	Coal	Wood + Wood chips	Coal	Gas	Wood + wood chips	Straw	Waste	Biogas	Natural gas				
Electricity mix	12%	0%	19%	5%	3%	1%	6%	3%	1%	4%	2%	42%	2%
Electricity efficiency	43%	43%	34%	34%	34%	34%	34%	37%	37%	43%	-	-	-

France

In the E+C- label, the electricity mix is not indicated but environmental indicators are provided for various uses of electricity: heating, cooling, domestic hot water, lighting and other uses, for housing and tertiary buildings.

In the EQUER design tool, the user can input a present constant electricity mix for heating and for other uses, or choose a variable mix (see below). The annual average mix in 2018 is 71.7% nuclear plants, 12.4% hydro-electricity, 7.2% gas and coal thermal plants, 5.1% wind, 1.9% PV and 1.8% bioenergies.

Hungary

In Hungary, nuclear power, fossil fuels and import dominate the electricity mix, with shares of 34%, 26% and 34%, respectively, in 2018 in the supply mix (MAVIR 2019). Renewables account only for 4% and 2% come from other sources. The life cycle based non-renewable cumulative energy demand was 12.1 MJ-eq/kWh and GHG emissions were 486 g CO_2-eq/kWh (Kiss et al. 2019) in 2018. With these values, Hungary is slightly above the average of the UCTE countries.

As there is no standard national assessment data, LCA practitioners/ researchers generally use data available in generic databases for the electricity mix. In studies by different researchers, different electricity mix, in some cases older datasets are applied, depending on the database available to the researcher.

Table 7: Life cycle environmental impact of the Hungarian average annual electricity mix 2018, reference unit: 1 kWh electricity supplied to the low voltage customers (Kiss et al. 2019)

Indicator	Unit	Supply mix
Cumulative energy demand, non renewable	MJ-eq/ kWh	12.1
Climate change – GHG emissions (GWP 100)	g CO_2-eq/kWh	485.8
ReCiPe-Endpoint (2016), total	1000 Points/ kWh	50.5

Switzerland

The Swiss average annual electricity mixes were last updated in 2020 and cover the year 2018 (Krebs & Frischknecht 2020). In Switzerland five different annual average mixes are distinguished: the production mix (electricity produced with power plants located in Switzerland), the suppliers mix (electricity delivered to customers in Switzerland), the average electricity product based on renewable energies, the consumer mix (suppliers mix minus electricity products from renewable energies) as well as the production mix including commercial trade.

In Switzerland, electricity is mainly produced with hydroelectric power plants (56.0 %), nuclear power plants (37.6 %) and from wastes (1.9 %). The Swiss suppliers' electricity mix is distinctly different from the production mix. The share of hydroelectric power plants (56.0 %) is the same but the share of nuclear power plants (18.4 %) is distinctly lower in the suppliers mix compared to the production mix. This is due to substantial GO imports (29.3 %) from renewable (17.7 %), non-renewable (1.6 %) and non-verifiable[22] (6.7 %) power plants.

The average Swiss electricity product based on renewable energies is composed of 94.4 % hydroelectric power, 2.7 % domestic PV electricity, 1.8 % domestic and foreign wind power and electricity from further renewable sources (about 1.0 %). The Swiss average annual consumer mix contains less hydroelectric power (39.8 %), because a substantial share of Swiss hydroelectric power is sold separately with dedicated electricity products. The shares in nuclear power (26.1 %) and of imports (36.4 %) in the consumer mix are significantly higher than in the suppliers mix.

Table 8 shows the environmental impacts of the four different Swiss average annual electricity mixes 2018.

Table 8: Environmental impacts of the Swiss average annual electricity mixes 2018, reference unit: 1 kWh electricity supplied to the low voltage customers (Krebs & Frischknecht 2020)

Indicator	**Unit**	**Production mix**	**Supply mix GO**	**Electricity product based on renewable energies**	**Consumer mix GO**	**Production plus commercial trade**
Greenhouse gas emissions	g CO_2-eq/kWh	29.6	54.7	15.7	71.0	128.0
Cumulative energy demand, non renewable	kWh oil-eq/kWh	1.65	1.08	0.04	1.51	2.08
Cumulative energy demand, renewable	kWh oill-eq/kWh	0.70	0.91	1.17	0.81	0.59
Environmental impacts (ecological scarcity 2013)	UBP/kWh	208	165	48	215	324

The greenhouse gas emissions of the average Swiss electricity product based on renewable energies and the Swiss production mix amount to 15.7 g CO_2-eq/kWh and 29.6 g CO_2-eq/kWh, respectively. The greenhouse gas emissions of the average suppliers and consumer mixes based on GO are substantially higher (54.7 g CO_2-eq/kWh and 71.0 g CO_2-eq/kWh). The significant increase compared to the production mix is mainly caused by the import of electricity from non-verifiable sources and, to a minor extent from known fossil-thermal power plants. The Swiss annual electricity mix 2018 based on production plus commercial

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[22] The non-verifiable power plants are modelled with the Swiss Residual mix 2018.

trade emits 128 g CO_2-eq/kWh, thus more than double the amount emitted by the Swiss supply mix 2018 based on GO.

The cumulative energy demand, non-renewable of the production, the suppliers, and the consumer electricity mix amounts to 1.65, 1.08 und 1.51 kWh oil-eq/kWh, respectively. The cumulative energy demand, non-renewable of the Swiss annual mix 2018 based on production and commercial trade is much higher with 2.08 kWh oil-eq/kWh whereas the CED non renewable of the average Swiss electricity product based on renewable energies is much lower with 0.04 MJ oil-eq/kWh. Nuclear power and electricity imports from unknown sources are the main drivers of the cumulative energy demand of Swiss electricity.

The environmental impacts of the average Swiss electricity product based on renewable energies quantified with the Swiss eco-factors 2013 of the ecological scarcity method amount to 48 eco-points/kWh and are much lower than the environmental impacts of the other mixes. The environmental impacts of the production, the suppliers, the consumer and the annual mix based on production and commercial trade are at 208, 165, 215 and 324 eco-points /kWh, respectively. The specific environmental impacts of electricity from hydroelectric and other renewable power plants are low. Nuclear power plants and imports from non-verifiable power plants as well as the electricity grid cause the main share of environmental impacts.
Most life cycle assessment studies, including the building sector, apply the consumer mix based on GO to model the electricity demand during operation of buildings located in Switzerland and in manufacturing construction materials produced in Switzerland. In 2021 the consumer mix will be represented by the annual mix based on production and commercial trade.

Sweden

The most commonly used emission factor for the Swedish annual average electricity mix is based on the work of the EU Joint Research Center (JRC) (Moro & Lonza, 2018). This represents the Swedish production mix, subtracting exports and adding imports and including grid losses. The calculation is based on data from IEA, ENTSO-E and Eurostat (European Network of Transmission System Operators, 2020; Eurostat, 2020; International Energy Agency, 2015). As of the beginning of 2020, the commonly used value is still based on the JRC calculation mentioned above, which relies on data for the year 2013. However, an updated value for the year 2018 is used for the development of the NollCO_2 certification. The value for 2013 is 47 gCO_2e/kWh for the supply mix (considering production, imports, exports and losses) and 25 gCO_2e/kWh for the production mix (considering only production and losses; this value is not commonly used). The updated value for 2018 for the supply mix is 22 gCO_2e/kWh (the difference is explained primarily by the fact that Sweden imported more electricity from Norway in 2018, and the Norwegian electricity mix has a comparatively low emission factor).

It should be noted that some other Swedish studies (e.g. Erlandsson, Sandberg, Berggren, Francart, & Adolfsson, 2018), as well as the Tidstegen tool for consequential assessments of energy solutions (Gode et al., 2015), use a Nordic electricity mix rather than a Swedish mix. The Nordic scope is also used within the Fossil Free Sweden initiative to develop a method for voluntary assessments of greenhouse gas emissions within the construction and infrastructure sector (although the development of this method is at an early stage)[23]. The Nordic scope represents the supply of electricity on the common market Nordpool. However, the Swedish Energy Agency now recommends the use of a national electricity mix, in accordance with practices in other European countries.

Norway

There is no average emission factor for the electricity in Norway. But the disclosure of electricity for Norway gives two emission factors, depending on whether the consumer has purchased a GO or not. For 2019 the emission factor for electricity was 18,9 g CO2eq/kWh with GO and 529 g CO2eq/kWh without GO. In the Norwegian standard NS3720:2018 („Method for greenhouse gas calculations for buildings“) requires the use

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[23] http://fossilfritt-sverige.se/fardplaner-for-fossilfri-konkurrenskraft/fardplaner-for-fossilfri-konkurrenskraft-byggbranschen/

of the future Norwegian production mix (2050, 18 g CO_2/kWh) or a future European electricity mix (2050, 136 g CO_2/kWh).

B.3 Future electricity mixes

Denmark

The LCA data for Danish electricity supply and district heating for use in LCAbyg was developed by Cowi consulting in 2016 (COWI 2016). Table 10 shows the electricity mix for the dataset representing the forecasting scenario for year 2015-2050. Based on this data environmental impact categories are calculated. The table shows an example for GHG emissions but other environmental impact categories are calculated as well.

Data for year 2015, 2020 and 2025 are from "Denmark's Climate and Energy Projection 2014". For year 2035 and 2050, data is calculated on the basis of "Energy scenarios against 2035 and 2050" as an average between the so-called wind scenario and the so-called biomass scenario.

CHP and condensation reflect different operating patterns. During condensation operation, only electricity (with a relatively high efficiency) is produced. In cogeneration operations, both electricity and district heating are produced (where the electricity efficiency is slightly lower, while, on the other hand, one uses more of the fuel by simultaneously producing district heating).

Allocation of potential environmental impacts between electricity and district heating is included in the data submitted by the Danish Energy Agency before the initiation of the emission factors. This allocation is expressed via the efficiencies.

Generally, the inventory is based on the technologies used today. Therefore, it is assumed that a potential production expansion could be carried out with the existing production equipment or similar equipment. In addition, the efficiencies for the individual types of plants do not change over time from 2015 to 2050 according to data from the Danish Energy Agency (COWI 2016).

Table 9: Electricity mix in percentages (%) in Danish electricity production for LCA dataset representing year 2015 (COWI 2016). Greenhouse gas emissions in g $CO_{2\text{-equivalents}}$ in parenthesis.

	Condense (steam turbine)		CHP (steam turbine)					Engine					
Year (and GHG emissions)	Coal	Wood + Wood chips	Coal	Gas	Wood + wood chips	Straw	Waste	Biogas	Natural gas	Gas turbine	Industry + bio factories	Wind	PV
2015 (352)	12%	0%	19%	5%	3%	1%	6%	3%	1%	4%	2%	42%	2%
2020 (201)	9	0	6	2	11	1	5	1	5	2	2	53	3
2025 (169)	9	0	4	1	12	1	5	1	3	3	2	56	4
2035 (31)	0	9	0	0	11	0	6	6	0	0	1	65	2

2050 (24)	0	9	0	0	1	0	5	3	0	1	2	76	3

France

In the EQUER design tool, the user can input a constant future electricity mix for heating and for other uses, or choose a variable mix (see below). Scenarios for a future mix have been elaborated by various organisations, e.g. the French Transmission System Operator (RTE) and the Agency for energy management and environment (ADEME).

Hungary

In the South East Europe Electricity Roadmap (Szabó et al. 2017) project three different scenarios were established for the development of the Hungarian electricity mix until 2050. In the "No target" scenario, no long-term goal is set for carbon-dioxide emission reduction. In the "Decarbon" scenario an emission reduction target of 94% is set for 2050 compared to the 1990 emission levels in line with the goals of the European Union. In the "Delayed" scenario, policy makers react to the European goals but with less intensity in the first years and a significant increase in renewables from 2035.

The forecast for the electricity mix was developed by the interaction of the European Electricity Market Model (EEMM) of the Regional Centre for Energy Policy Research (REKK), and the Green-X model, developed by the Energy Economics Group of the Vienna University of Technology. Based on this forecast, an environmental assessment has been carried out (Kiss et al. 2019).

All scenarios achieve a reduction in the environmental impact of electricity supply, but there are significant differences between the different scenarios. Depending on the scenario, the GHG emissions are expected to decrease to 340 or 42 g/kWh in the No target and the Delayed scenario, respectively. All the three scenarios included nuclear-based generation based on the latest available information on the decommissioning and commissioning date of "Paks 1" (existing) and "Paks 2" (planned) nuclear power plants. The two power plants (or at least some of their blocks) will operate in parallel between 2030 and 2036. The nuclear share is around 35% in all long-term scenarios, except in the years of parallel operation.

Table 10: Life cycle environmental impact of 1 kWh supplied electricity, low voltage for three different future scenarios for 2050 (Kiss et al. 2019)

Indicator	Unit	No target scenario	Decarbon scenario	Delayed scenario
Cumulative energy demand, non renewable	MJ-eq/ kWh	11.1	7.7	7.5
Climate change – GHG emissions (GWP 100)	g CO_2-eq/kWh	340.8	63.7	42.1
ReCiPe-Endpoint, total (2016)	1000 Points/ kWh	34.8	8.15	6.1

Switzerland

The future average annual electricity mix of Switzerland is based on the energy strategy 2050 scenarios of the Swiss Government (Prognos 2012). The LCA of these electricity mixes is published in Wyss et al. (2013).

In 2011 the exit from nuclear power was declared. In regard for a sustainable and 'green' future, Switzerland outlined different options for prospective energy strategies and securitiy of energy supply. In this context the Swiss Federation elaborated the Energy Strategy 2050, in which three different scenarios for possible future energy situations were designed. The scenarios are 'business as usual' (WWB), 'new energy policies' (NEP) and ‘political measures’ (POM). The scenarios differ in energy policies, electricity demand, production volumes and the technological mix for achieving security of energy supply.

This study analyzes environmental impacts of three electricity mixes in 2050, according to the scenarios. The analysis is conducted for the year 2050 and for Switzerland. The functional unit of this study is 1 MJ of electricity consumed in Switzerland (low voltage). The environmental impact categories greenhouse gas emissions (based on GWP 100), ‘cumulative energy demand’ (CED) and ecological scarcity 2006 were assessed.

The electricity production was modelled with present technologies. However the shares per production technology comply with the year 2050 (in accordance with the scenarios from the Energy Strategy 2050). Two data-sets are generated: one regards only domestic production and one includes electricity trade according to present trade volumes. Electricity import and trade is modeled based on scenario information about the European electricity mix in 2050. For the three scenarios WWB, NEP and POM dedicated and consistent European mixes were chosen. Within the scenarios NEP and POM, European coal and natural gas fired power plants are equipped with carbon capture and storage (CCS). Table 11 shows a comparison of all three scenarios and the indicators analyzed for the electricity mixes in 2050 as well as the environmental impacts of the present electricity mix in Switzerland and Europe. Figure 10 to Figure 12 show a graphical comparison of the environmental impacts of the electricity mixes with and without trade.

Table 11: Summary of the life cycle based cumulative environmental impacts of electricity mixes according to the scenarios in the Energy Strategy 2050, per MJ electricity, low voltage

Electricity mix	**Primary energy total** MJ oil-eq/MJ	**Primary energy non-renewable (fossil and nuclear)** MJ oil-eq/MJ	**Primary energy non-renewable - fossil** MJ oil-eq/MJ	**Primary energy non-renewable - nuclear** MJ oil-eq/MJ	**Primary energy renewable** MJ oil-eq/MJ	**Primary energy waste/ wasteheat** MJ oil-eq/MJ	**Carbon dioxide fossil** g CO_2-eq/MJ	**Greenhouse gas emissions** g CO_2-eq/MJ	**Ecological scarcity** eco-pt/MJ
WWB, option C	1.67	0.96	0.94	0.02	0.72	0.00	54.2	59.2	39.5
NEP, option C+E	1.38	0.28	0.26	0.02	1.09	0.00	17.0	21.2	26.6
POM, option E	1.40	0.29	0.23	0.06	1.11	0.00	12.8	16.9	26.8
WWB incl. trade, option C	2.20	1.61	1.28	0.32	0.59	0.00	86.9	93.7	76.9
NEP incl. trade, option C+E	1.58	0.41	0.39	0.02	1.18	0.00	23.4	27.5	32.7
POM, incl. trade, option E	1.92	1.06	0.69	0.38	0.86	0.00	16.8	21.8	45.1
CH-Production mix[1]	2.41	1.76	0.10 [2]	1.65 [2]	0.65 [2]	-	0.007 [2]	8.3	75.7
CH-Supply mix[1]	3.05	2.63	0.51 [2]	2.13 [2]	0.42 [2]	0.02 [2]	0.038 [2]	41.3	125
UCTE-Mix[1]	3.54	3.32	2.01 [2]	1.32 [2]	0.22 [2]	-	0.156 [2]	165.0	177

[1] data from the KBOB recommendation 2009/1, July 2012 (KBOB et al. 2012)

[2] data from Frischknecht & Itten (2011)

The electricity mix of the scenario NEP has the lowest environmental impacts regarding CED and ecological scarcity. Within the NEP scenario a strict policy for renewable energy is proclaimed. Hence the electricity mix of the NEP scenario has the highest share of renewable energy sources and only little fossil fuels. As there is no import, there is no electricity from european nuclear or coal power. The electricity mix of the POM scenario has a slightly lower share of renewable energy sources compared with the electricity mix of the NEP scenario. It contains hardly any fossil fuel based electricity. Furthermore about 9 % of the electricity is imported. European fossil fuel based power plants in the electricity mix imported are equipped with CCS-technologies. In consequence the electricity mix of the scenario POM causes slightly lower greenhouse gas emissions compared to the electricity mix of the NEP scenario.

The use of fossil fuels has a large impact on the indicators GHG emissions and CED. Hence the electricity mix of the scenario WWB, which has no particular emphasis on renewable electricity, causes higher environmental impacts (all indicators) than the electricity mix of the NEP or POM scenarios.

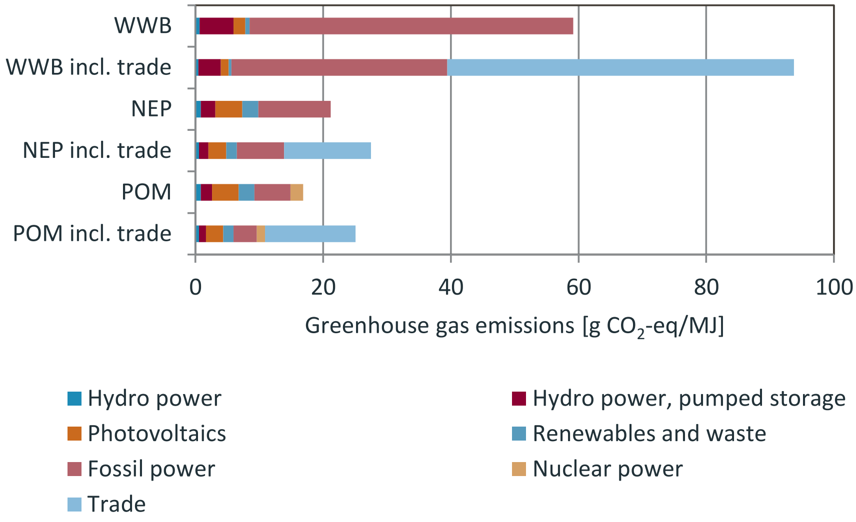


Figure 10: Greenhouse gas emissions of the electricity mixes, with and without trade

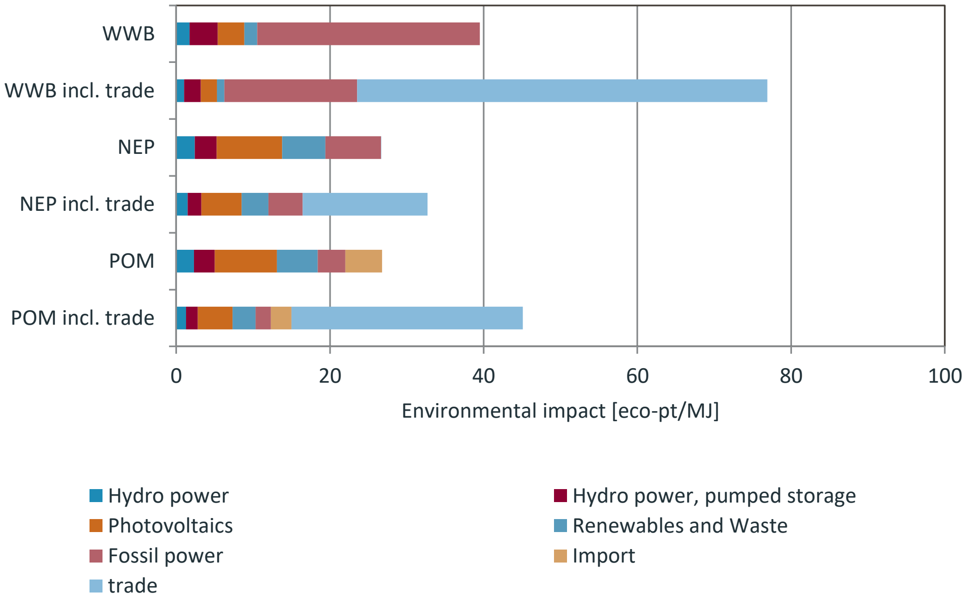


Figure 11: Environmental impacts of of the electricity mixes, with and without trade, ecological scarcity method 2006

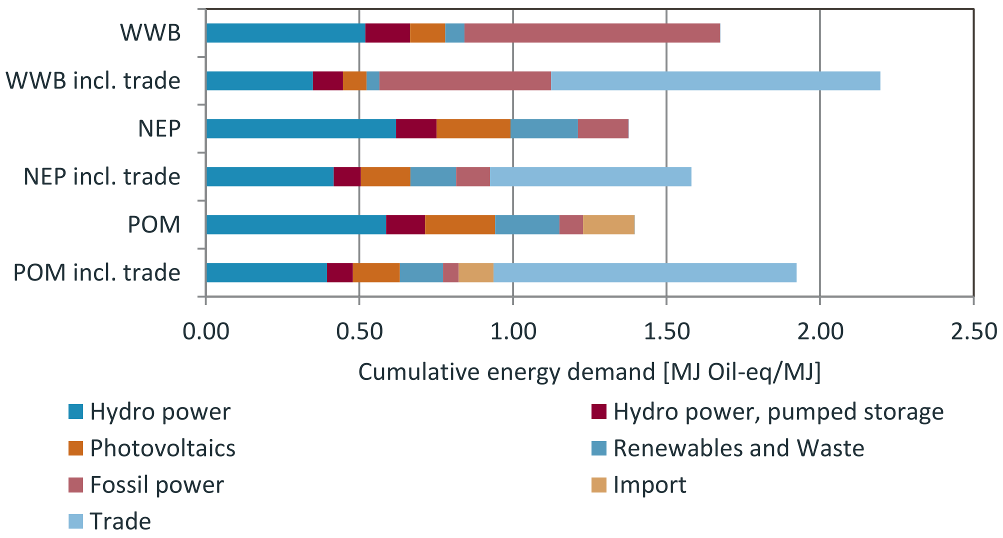


Figure 12: Cumulative energy demand of the electricity mixes, with and without trade

The environmental impacts of the aspired electricity mixes in the year 2050 are clearly lower than those in Switzerland in 2009 (production mix as well as supply mix). However the current production mix causes lower greenhouse gas emissions than any of the three future electricity mixes, due to todays share of domestic electricity production from hydroelectric and nuclear power. At the same time, nuclear power is the main reason for the high environmental impacts of the current electricity mixes. The ENTSO-E electricity mix causes the highest amount of greenhouse gas emissions and the largest environmental impacts. The share of non renewable energy sources in the year 2050 decreases about 45 to 84 % (depending on the scenario) compared to the present Swiss production mix.

The environmental impacts with electricity trade are larger than without trade. This is especially true for the electricity mix of the scenario WWB, which has a large share of fossil fueled electricity produced without CCS-technologies. It is noticeable, that POM electricity has the lower global warming potential than NEP electricity (both including trade). This results from the lower share of fossil fueled domestic electricity production and the high share of imported electricity, which includes fossil fueled electricity produced with CCS-technologies. These come with low CO_2-emissions.

Sweden

It is not yet common to include future scenarios for the energy mix in building LCAs in Sweden, but several recent initiatives are taking up this issue. First, a recent report includes a model to assess future greenhouse gas emissions from the Swedish building sector, including a future scenario for the energy supply (Erlandsson, 2019). This scenario is based on long-term forecasts from the Swedish Energy Agency (Swedish Energy Agency, 2019). It leads to an emission factor for Swedish electricity of 36 gCO_2e/kWh in 2035 and 22 gCO_2e/kWh in 2050. Second, assessments in the upcoming NollCO_2 certification system use a future emission factor based on forecasts from the European Union until 2050. Electricity production in Sweden and the rest of Europe is assumed to be carbon-neutral in 2050, in accordance with long-term strategies from Sweden and the EU. The emission factor of electricity is assumed to decrease linearly between 2020 and 2050, reaching 0 in 2050. Since these forecasts lead to decreasing emission factors for electricity, one of the consequences is that environmental benefits from exported PV power decrease over time (since NollCO2 relies on an avoided burden approach taking into account potentially avoided emissions from locally produced electricity exported to the grid). Third, the Tidstegen (time step) tool for consequential assessments of energy measures considers three future scenarios for the Nordic electricity mix, up to 2040. The scenarios differ notably regarding assumptions about the cost of carbon emissions in the future. A linear programming model is used to asses the consequences of a change in demand on different production technologies, depending on the year, the season and the time of day when this change happens. The

Tidstegen tool calculates a marginal electricity mix including both short term and long term effects, for each of these time steps (Gode et al., 2015).

A previous work had also been carried out to develop hourly average and marginal future mixes for the Nordic electricity market, based on a scenario from the International Energy Agency (Erlandsson et al., 2018; International Energy Agency, 2016). However, results from this work are usually not used in other assessments. A number of other future scenarios have been developed in Sweden, including backcasting scenarios (i.e. scenarios where a specific goal is fulfilled), e.g. Four Futures (Swedish Energy Agency, 2016) and Beyond GDP Growth (Gunnarsson-Östling et al., 2017). Such scenarios represent developments of the energy system that are possible, but not necessarily likely. Therefore, they are usually not used in LCA.

Norway

The Norwegian Standard on LCA of buildings (NS3720:2018) has two scenarios for future electricity mix;

- Scenario 1 – NO, which gives an average CO_2 emission factor for Norwegian el. production from 2015 to 2075 of 18 g CO_{2eq}/kWh.This value calculation is based on the median values from Turconi et.al (2013).
- Scenario 2 – EU28+NO, which gives an average CO_2 emission factor for European el. production from 2015 to 2075 of 136 g CO_{2eq}/kWh. This value is calculated on basis of values from Eurostat, the EU Roadmap 2050 and Turconi et.al (2013).

The EU value does correspond to the CO_2 factor used by the Research Centre on Zero-Emission Buildings (ZEB), in the LCA for the validation of the “Zero-emission”. The ZEB framework uses a CO_2-factor of 132 g CO2eq/kWh, which is a modelled average CO_2-factor from Europe production between 2010 and 2050 (Graabak et al 2014).

However, the values for the future Norwegian production mix is much lower than the disclosure of the Norwegian electricity consumption. So in order to use Scenario 1, users has to purchase a Garantie of origien for the electricety.

B.4 Seasonal (summer/winter) average electricity mix

Denmark

No dataset available.

France

Seasonal average is not used in France, but the constant mixes defined according to the use (heating, cooling etc.) in E+C- correspond to a similar concept. The average mix is evaluated according to a consumption profile of a building type (housing or tertiary) and an electricity use (heating, hot water, lighting etc.).

Hungary

Analysis of the current electricity supply shows that the seasonal variation of the supply is very small. The difference between the environmental impact of electricity in the heating and the non-heating seasons is negligible. This is explained by the fact that the share of renewables, which have a seasonal variation, is very small in the Hungarian supply mix.

Some difference can be observed between the environmental impact in different months, mostly due to a slight variation in the relative contribution of nuclear power plants and a slight increase in renewables in the summer. In the future electricity mix with more renewables, the difference between months is expected to grow (Kiss et al 2020).

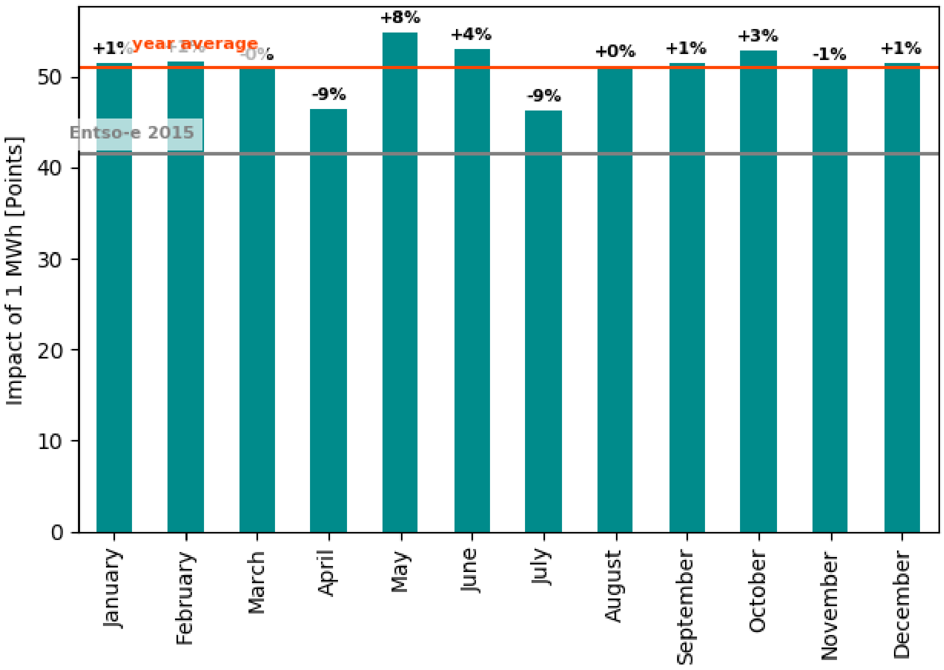


Figure 13: Average environmental impact of the electricity mix in each month for year 2018 compared to the year average, “Decarbon” scenario, ReCiPe Endpoint total indicator (Kiss et al. 2019)

Switzerland

No dataset available yet.

Sweden

The seasonal variability of the energy supply is usually not taken into account in Swedish LCAs. The Tidstegen (time step) method tackled this issue for consequential LCAs of building energy solutions (Gode et al., 2015). The Tidstegen method has not seen much application in Sweden, but has recently been published as a free software tool, which might increase its adoption (Gode, Nilsson, Ottosson, & Sidvall, 2019).

The general assumption in Tidstegen is that time resolution does not matter in the short term, i.e. a change in energy demand in a building will have the same impact in the coming 5-15 years regardless of whether it happens in winter or summer, during peaks or off-peak. The main justification for this assumption is the large share of hydropower on the Nordic grid, which can regulate seasonal and hourly changes in demand. Since the yearly output of hydropower is limited, an increase in demand will result in an overall increase in importation of electricity produced with fossil fuels in Denmark or Germany, regardless of the season or time of day when this increase in demand happens.

However, in the long term, time resolution matters, and the marginal mix depends on how supply and demand will evolve in the future. A change in electricity demand will have different short- and long-term consequences, depending on the year, season and time of day (daytime or nighttime) when it happens. Three future scenarios are used. A different marginal mix taking into account short- and long term effects (and a corresponding emission factor) is calculated for each time step and each scenario. A measure is assumed to have positive (resp. negative) environmental effects if its effects are positive (resp. negative) in most scenarios.

Seasonal aspects are even more significant when assessing the impact of heating (in Sweden, district heating is the prominent solution). Gode et al. (2015) then use dynamic emission factors for heating depending on outside temperature.

B.5 Hourly resolution of the electricity mix

Denmark

No dataset available.

France

Hourly values of electricity production using different technologies are provided by the French Transmission System Operators (RTE). The data includes imported quantities from different countries. Using some assumption regarding imported electricity (e.g. yearly average production mix corresponding to the exporting country), the mix corresponding to consumed electricity has been estimated for past years. The quantity of imported electricity was 5.5% of the consumption in 2018.

An electric system model has been developed (Roux et al. 2017) in order to evaluate hourly mix values according to energy transition scenarios and climatic data. This model has been linked to the Building LCA tool EQUER. Energy consumption in buildings is generally estimated using "typical meteorological years" (TMY), corresponding to a statistical average of e.g. 20 real years. The electricity supply mix corresponding to such TMY is evaluated on an hourly basis using the electric system model. Energy transition scenarios may provide installed capacities in future years, and the corresponding hourly mix can also be evaluated using the same electric system model. Effects of climate change on e.g. hydroelectric production can be taken into account.

This model has been complemented in order to integrate short term and long term temporal variation (Frapin et al., 2021) by connecting three models addressing: market allocation on a national scale over a long term period, short term variation (i.e. seasonal, daily and hourly) of the electricity mix also on a national scale, and building energy simulation at the scale of one building. The short term variation model has been updated using more recent data from the French TSO.

The bottom-up linear optimization model computes a least cost pathway for the electricity system subject to the satisfaction of specified service demands and user specified constraints, accounting for the interaction with the gas supply system. This allows for systemic description of gas-to-power and power-to-gas interactions. It also includes a new description of flexibility options on the demand-side which influence the penetration of renewables and the shape of the load. This optimisation process provides electricity production mix scenarios according to 4 main parameters regarding: the ambition level of the environmental policy (from 30 €/tCO_2 carbon penalty to carbon neutrality), technology acceptance (with or without carbon capture and storage, nuclear plants), acceptance of demand control technologies by end-users, and cost reduction scenario of solar and wind technologies. 50 energy transition scenarios have been developed by combining these 4 parameters.

Three LCA methods were used. The average approach, associated to attributional LCA evaluates an average electricity mix for each hour of the reference year, which is then linked to technologies life-cycle impacts per kWh. Associated to consequential LCA, two marginal approaches were compared. The first one evaluates a marginal electricity production using the electricity mix model to simulate an additional electricity demand evaluated for the studied project using the building energy simulation model. The second one uses the GHG Protocol procedure (GHG protocol, 2007) from a reference electricity production, ranking the technologies by merit-order and choosing a 10% operational margin. The first one is more accurate but also time-consuming; the second one is fast, more flexible (adaptable to electricity mix results from other models or scenarios) but less specific to a given project.

This methodology has been applied to a case study including a sample of buildings in the French context, but it can be used in other countries. Six buildings have been studied over 100 years considering the 50 energy transition scenarios mentioned above. Results show that the environmental impacts vary more depending on the scenarios than on building types. They depend on the use: for instance CO_2 emissions are higher for heating due to a larger use of thermal plants during winter peak demand periods, whereas avoided impacts considered for exported PV production mostly correspond to low demand periods in summer, during which low carbon electricity production capacities are available. Marginal mixes considered in consequential LCA are mainly composed of coal, gas, nuclear and peak technology production which explains the highest values of the different impacts compared to average mixes used in attributional LCA. The error bars correspond to upper and lower values for the 50 scenarios.

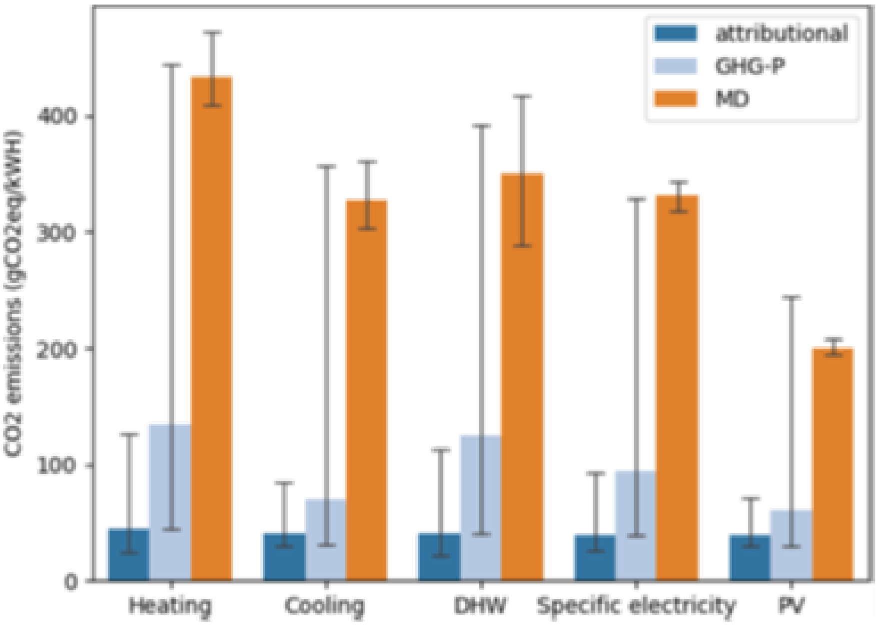


Figure 14a: Use specific CO2 emissions according to the LCA method (Frapin et al., 2021)

Impacts of universal mixes (average of all uses) obtained using the CMA market allocation model, considering a reference (C1) or reduced (C2) cost of wind and solar technologies, are compared to scenarios defined by the French environment agency (ADEME) and TSO (RTE).

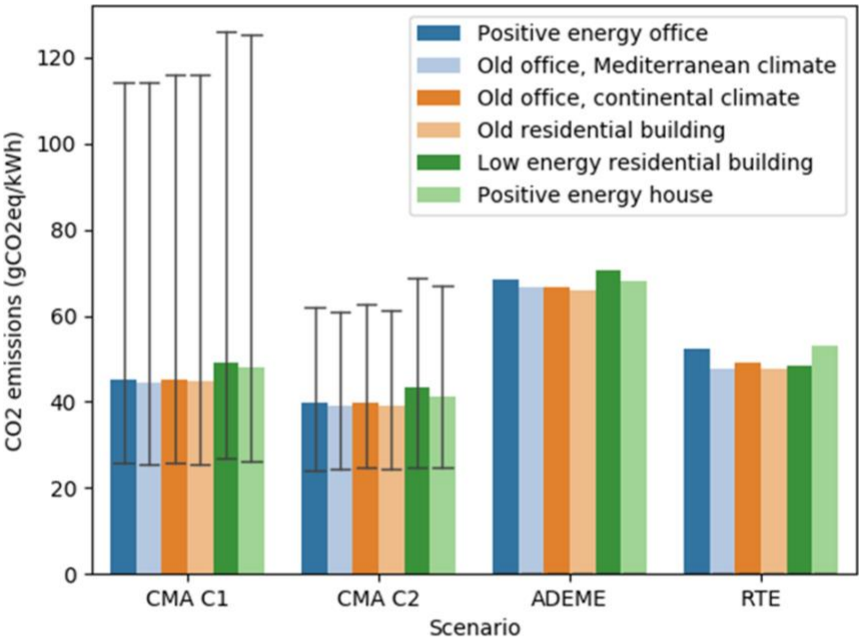


Figure 15b: Sensitivity analysis of GHG emissions to the scenario and type of building (attributional LCA) (Frapin et al., 2021)

This approach allows to address uncertainties related to electricity production over the long life span of buildings (100 years are considered in this study).

Hungary

In today's electricity mix in Hungary, the intra-annual variation of the environmental impact of electricity supply is ± 15% for CED n.r. and ± 30% for GHG emissions and ReCiPE. The coefficient of variation is 5% for CED, and 10% for GHG emissions and ReCiPe (Kiss et al. 2019).

The application of the European Electricity Market Model (EEMM) makes it possible to analyse the hourly resolution of the electricity mix also in the long term. Research shows that the coefficient of variation in the environmental impact of electricity is expected to significantly increase in the future due to decarbonization and a higher share of renewables (CV = 23% for CED n.r., 77% for GHG emissions, 59% for ReCiPe) (Kiss et al 2020). This suggest that in the future it will be even more important to consider the intra-annual variation of the electricity mix. Simplification to an annual mix may lead to under- and overestimations if electricity use is not constant during the year.

Switzerland

In hourly assessment, different examples of the physical approach can be mentioned including: the computational tool developed as part of the EcoDynbat project at HES-SO (Padey et al, 2020) and the ELCAB project led by Treeze Ltd.

EcoDynBat project, method & computational tool

The EcoDynBat research project (Dynamic LCA of buildings) funded by the Swiss Federal Office of Energy (SFOE) from 2018 to 2020 aims to assess the effect of different intra-annual time step on the environmental impacts of the Swiss building electricity demand.

To do so, a computational tool able the calculate the hourly LCA data of national electricity mixes for Switzerland and neighbouring countries was developed. It is based on empirical data provided by TSO and other sources for Switzerland and the neighbouring countries. Such hourly LCA data does not exist yet in Switzerland or at least does not exist at this level of details using a computational approach based on a matrix inversion (see below for more information) and hourly data for both domestic production means and imports from neighbouring countries. Different steps were conducted including:

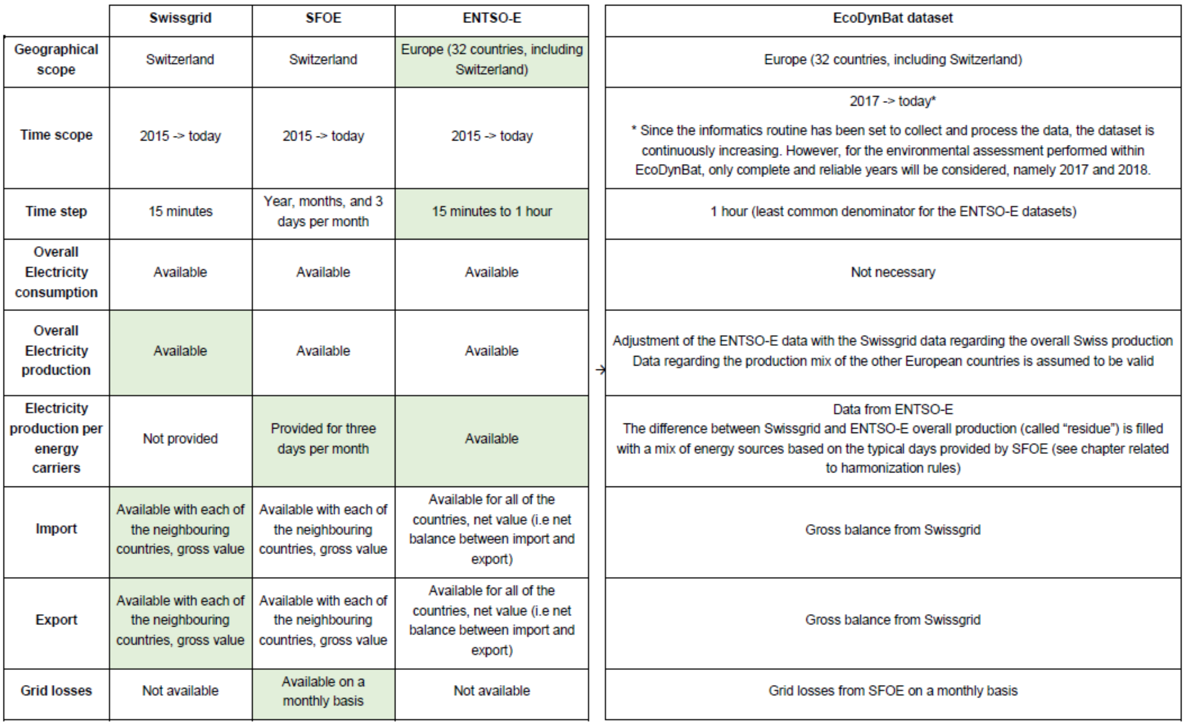
1. Data collection and adjustments
2. Matrix-based calculation based on hourly data for the electricity mixes
3. Use of the hourly electricity mix in the LCA of the energy use in Swiss buildings

<u>1) Data collection and adjustments</u>.

First, the hourly Swiss consumer mix has been defined for the years under study (e.g. 2017 and 2018). The mix is defined by considering the specific physical imports for each Swiss neighbouring countries (Germany DE, Italy IT, Austria AT and France FR) as well as Czech Republic (CZ). Indeed, a preliminary screening assessment has identified that the CZ contribution to the Swiss consumed electricity impact was significant because of the interaction of this country with Germany and Austria (cf. point 2 below for more information). The other exchanges with the neighbouring countries of AT, IT, DE, FR and CZ are also considered but the environmental impacts for these flows is assumed to be constant and to correspond to the European average electricity (from ecoinvent V3.4).

The hourly Swiss consumed electricity has been defined based on various data sources. The backbones rely on the ENTSO-E data which provides the production mixes for the different European countries as well as the physical cross boarder exchanges. Nevertheless, this data source has been found to be partially matching the EcoDynBat project objectives. First, the cross boarder exchange considered within ENTSO-E are net exchanges. Thus, the cross boarder exchanges have been modified in order to consider the gross exchanges (i.e., the import and exports at the Swiss borders) and fulfil the project scope.

The data from Swissgrid, the Swiss TSO have been use for this purpose. Then, a comparison for the production mixes with the national data sources has been performed. While the ENTSO-E data shows a correct adequacy compared to the national datasets for France, Italy, Germany and Austria, the Swiss data from ENTSO-E shows some inconsistencies compared to the national statistics from the Swiss Federal Office for Energy (SFOE). There are indeed significant differences between the ENTSO-E data and the national SFOE data for the hydroelectricity from run-of river and photovoltaic production means. The ENTSO-E data has been adjusted by correcting the production volume of these two production means with the data from the Swiss Energy statistics published by the SFOE for representative days in the year.
The next table summarizes this first important step.



	Swissgrid	SFOE	ENTSO-E	EcoDynBat dataset
Geographical scope	Switzerland	Switzerland	Europe (32 countries, including Switzerland)	Europe (32 countries, including Switzerland)
Time scope	2015 -> today	2015 -> today	2015 -> today	2017 -> today* * Since the informatics routine has been set to collect and process the data, the dataset is continuously increasing. However, for the environmental assessment performed within EcoDynBat, only complete and reliable years will be considered, namely 2017 and 2018.
Time step	15 minutes	Year, months, and 3 days per month	15 minutes to 1 hour	1 hour (least common denominator for the ENTSO-E datasets)
Overall Electricity consumption	Available	Available	Available	Not necessary
Overall Electricity production	Available	Available	Available	Adjustment of the ENTSO-E data with the Swissgrid data regarding the overall Swiss production Data regarding the production mix of the other European countries is assumed to be valid
Electricity production per energy carriers	Not provided	Provided for three days per month	Available	Data from ENTSO-E The difference between Swissgrid and ENTSO-E overall production (called “residue”) is filled with a mix of energy sources based on the typical days provided by SFOE (see chapter related to harmonization rules)
Import	Available with each of the neighbouring countries, gross value	Available with each of the neighbouring countries, gross value	Available for all of the countries, net value (i.e net balance between import and export)	Gross balance from Swissgrid
Export	Available with each of the neighbouring countries, gross value	Available with each of the neighbouring countries, gross value	Available for all of the countries, net value (i.e net balance between import and export)	Gross balance from Swissgrid
Grid losses	Not available	Available on a monthly basis	Not available	Grid losses from SFOE on a monthly basis

Figure 16: Summary of the EcoDynBat dataset choice, in green the chosen route from the literature sources (Swissgrid, SFOE, ENTSO-E); figure taken from the final report of the EcoDynBat project

Based on these different data choices and adjustments, and including the conversion losses from high voltage to low voltage, the overall Swiss consumed electricity mix has been obtained, based on an empirical approach using, for this contribution to IEA-EBC Annex 72 project, existing data for the years 2017 and 2018[24], Figure 17.

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[24] The approach allows to regularly update the Swiss electricity hourly dataset in the future as so far only the two first years (2017 and 2018) are available in an appropriate format especially from ENTSO-E (as it is a relatively recent initiative).

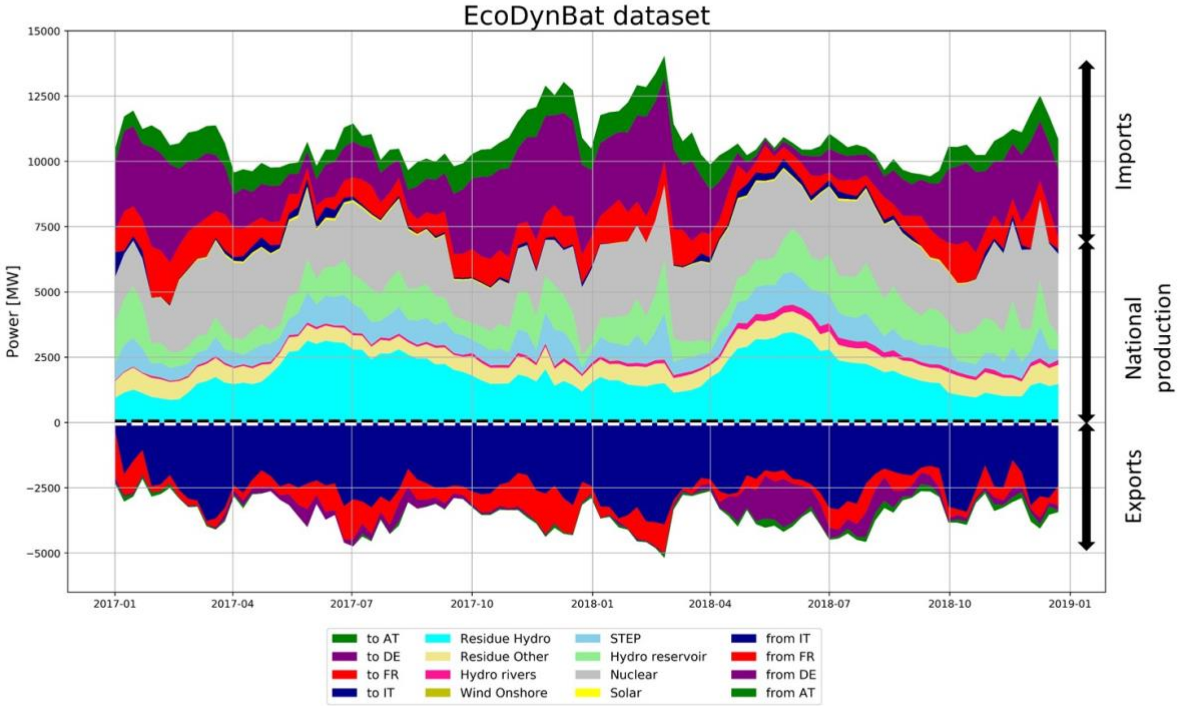


Figure 17: Swiss electricity flows; results given for the years 2017-2018

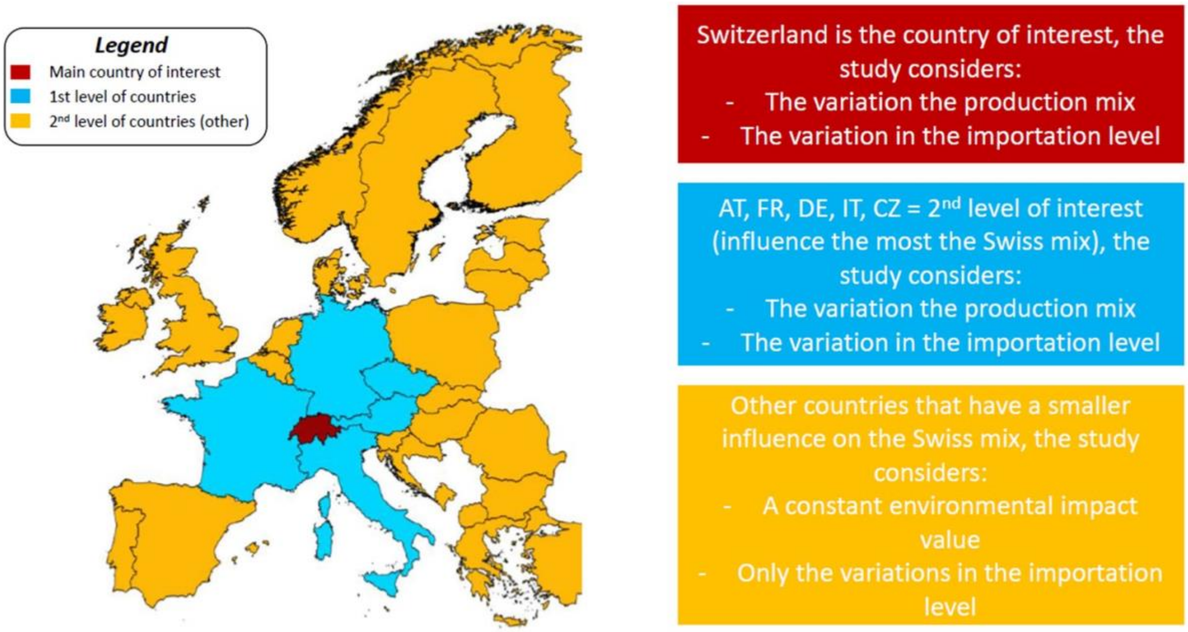
2) Matrix-based calculation to calculate the Swiss consumption mix

Then, a matrix-based approach has been used in order to calculate the contribution of each production means to the environmental impact of the Swiss consumed electricity. Generally speaking, the algorithm is able to calculate 1 kWh of consumption mix for all the European countries considered in the EcoDynBat approach. As in any matrix-based calculations, the user just needs to define the reference flow e.g., 1 kWh of consumption mix for Switzerland. Then, the matrix-based framework will perform the calculation using hourly data for all European countries.

However, in order to avoid running such a large dataset with hourly data of all European countries, a preliminary contribution analysis of impacts from countries' mixes in a standard LCA of the annual Swiss mix show that only six countries (AT, FR, DE, IT, CZ) as well as Switzerland are contributing to the total Life Cycle Impact Assessment (LCIA) indicators at 99% or above for the three commonly used indicators in the Swiss building sector: GHG emissions, Cumulative Energy Demand (CED), and the total environmental impact expressed as Ecological scarcity (UBP). All the other European countries contribute to less than 1% to the total impacts for all categories. The next table presents the obtained results:

Levels of details in the ecoinvent model of the consumers' mix	**Global warming potential**	**Cumulative energy demand**	**Ecological scarcity (UBP)**
Share of total impacts from CH production only	10.3%	65.0%	45.5%
Share of total impacts from CH production + imports from direct neighbors (FR, DE, IT, AT)	84.5%	95.5%	92.8%
Share of total impacts from CH production + imports from direct neighbors (FR, DE, IT, AT) + imports from AT, CH, DE, FR, IT in neighboring countries	91.4%	98.0%	96.3%
Share of total impacts from CH production + imports from direct neighbors (FR, DE, IT, AT) + imports from AT, CH, DE, FR, IT in neighboring countries + imports from CZ	98.8%	99.6%	99.5%
Share of total impacts for CH consumers' mix coming from other EU countries	1.2%	0.4%	0.5%

Finally, at each time step, a 144x144 matrix (corresponding to the production means of each considered countries, namely, DE, IT, AT, CH, CZ and FR as well as the gross cross boarder exchanges between each countries) is inversed to obtain the shares of the various production means to the Swiss consumed electricity. The next Figure presents these six countries of interest based on the initial contribution analysis including Switzerland.



Switzerland is the country of interest, the study considers:
- The variation the production mix
- The variation in the importation level

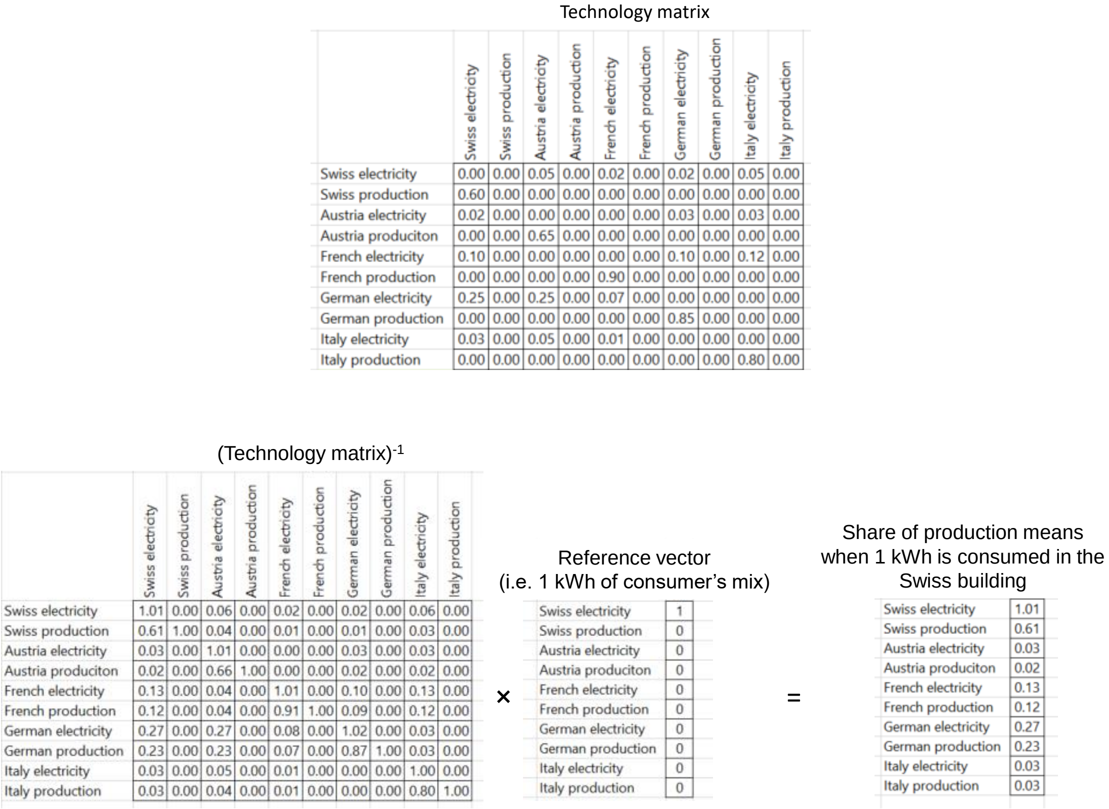
AT, FR, DE, IT, CZ = 2nd level of interest (influence the most the Swiss mix), the study considers:
- The variation the production mix
- The variation in the importation level

Other countries that have a smaller influence on the Swiss mix, the study considers:
- A constant environmental impact value
- Only the variations in the importation level

Figure 18: Graphical representation of the main country of interest and the first and second levels of countries depending on their LCIA contributions to the consumption mix of the main country of interest

Explanation of the matrix-based calculation in the Swiss EcoDynBat method in a simplified example:
The key concepts that regulate this approach are the electricity modeling approach “production + imports” and the interest to use a matrix-based structure. They are both used to consider the exchanges between the electricity mixes of the European countries. Consequently, all imports from neighbors of Switzerland will become a part of the consumer’s mix, which will then be used in Swiss buildings. The imports of these neighbors will also be considered, but in a simplified manner as an average ENTSO-E mix.

A simplified example of this matrix-based calculation is provided below. The main simplifications of this example are in the aggregation of production means for a country and a limited number of considered ENTSO-E countries. Moreover, such a calculation must be done for every time step over the year (i.e. 8760 calculations for the hourly resolution). In this example, values in the technology matrix represent the input process from that row into the process from that column. For instance, 0.6 kWh of produced electricity in Switzerland is needed for the Swiss electricity mix during that period as well as 0.2 kWh from Austria, 0.1 kWh from France, 0.25 kWh from Germany and 0.03 kWh from Italy. These are only the direct needs and uncovering the full energy requirements over the entire supply chain requires the step of matrix inversion. It is only then that this inversed technology matrix is multiplied by the reference vector to obtain the life cycle energy flows for the consumption of 1 kWh of electricity in Swiss buildings at a specific time step.



Technology matrix

	Swiss electricity	Swiss production	Austria electricity	Austria production	French electricity	French production	German electricity	German production	Italy electricity	Italy production
Swiss electricity	0.00	0.00	0.05	0.00	0.02	0.00	0.02	0.00	0.05	0.00
Swiss production	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Austria electricity	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00
Austria produciton	0.00	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
French electricity	0.10	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.12	0.00
French production	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00
German electricity	0.25	0.00	0.25	0.00	0.07	0.00	0.00	0.00	0.00	0.00
German production	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.00
Italy electricity	0.03	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Italy production	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00

(Technology matrix)$^{-1}$

	Swiss electricity	Swiss production	Austria electricity	Austria production	French electricity	French production	German electricity	German production	Italy electricity	Italy production
Swiss electricity	1.01	0.00	0.06	0.00	0.02	0.00	0.02	0.00	0.06	0.00
Swiss production	0.61	1.00	0.04	0.00	0.01	0.00	0.01	0.00	0.03	0.00
Austria electricity	0.03	0.00	1.01	0.00	0.00	0.00	0.03	0.00	0.03	0.00
Austria produciton	0.02	0.00	0.66	1.00	0.00	0.00	0.02	0.00	0.02	0.00
French electricity	0.13	0.00	0.04	0.00	1.01	0.00	0.10	0.00	0.13	0.00
French production	0.12	0.00	0.04	0.00	0.91	1.00	0.09	0.00	0.12	0.00
German electricity	0.27	0.00	0.27	0.00	0.08	0.00	1.02	0.00	0.03	0.00
German production	0.23	0.00	0.23	0.00	0.07	0.00	0.87	1.00	0.03	0.00
Italy electricity	0.03	0.00	0.05	0.00	0.01	0.00	0.00	0.00	1.00	0.00
Italy production	0.03	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.80	1.00

×

Reference vector
(i.e. 1 kWh of consumer's mix)

Swiss electricity	1
Swiss production	0
Austria electricity	0
Austria produciton	0
French electricity	0
French production	0
German electricity	0
German production	0
Italy electricity	0
Italy production	0

=

Share of production means
when 1 kWh is consumed in the
Swiss building

Swiss electricity	1.01
Swiss production	0.61
Austria electricity	0.03
Austria produciton	0.02
French electricity	0.13
French production	0.12
German electricity	0.27
German production	0.23
Italy electricity	0.03
Italy production	0.03

Figure 19: Simplified example of the matrix-based calculation to account all production means (taken from the final EcoDynBat SFOE final report)

The other details of the modelling characteristics of the EcoDynBat electricity mix is provided in Section 1.8 **Error! Reference source not found.**. It is an hourly mix calculated by adding the production mix plus imports. The results are then aggregated for the various time steps considered in the EcoDynBat project, i.e, Hourly, Daily, Monthly and Yearly time steps. The contribution to the Swiss consumed electricity mix per countries and per production means (renewable including hydropower (and named as "EnR" in the figure below), nuclear, pumping storage (STEP), fossil and "other non-identified") is given in the Figure 20.

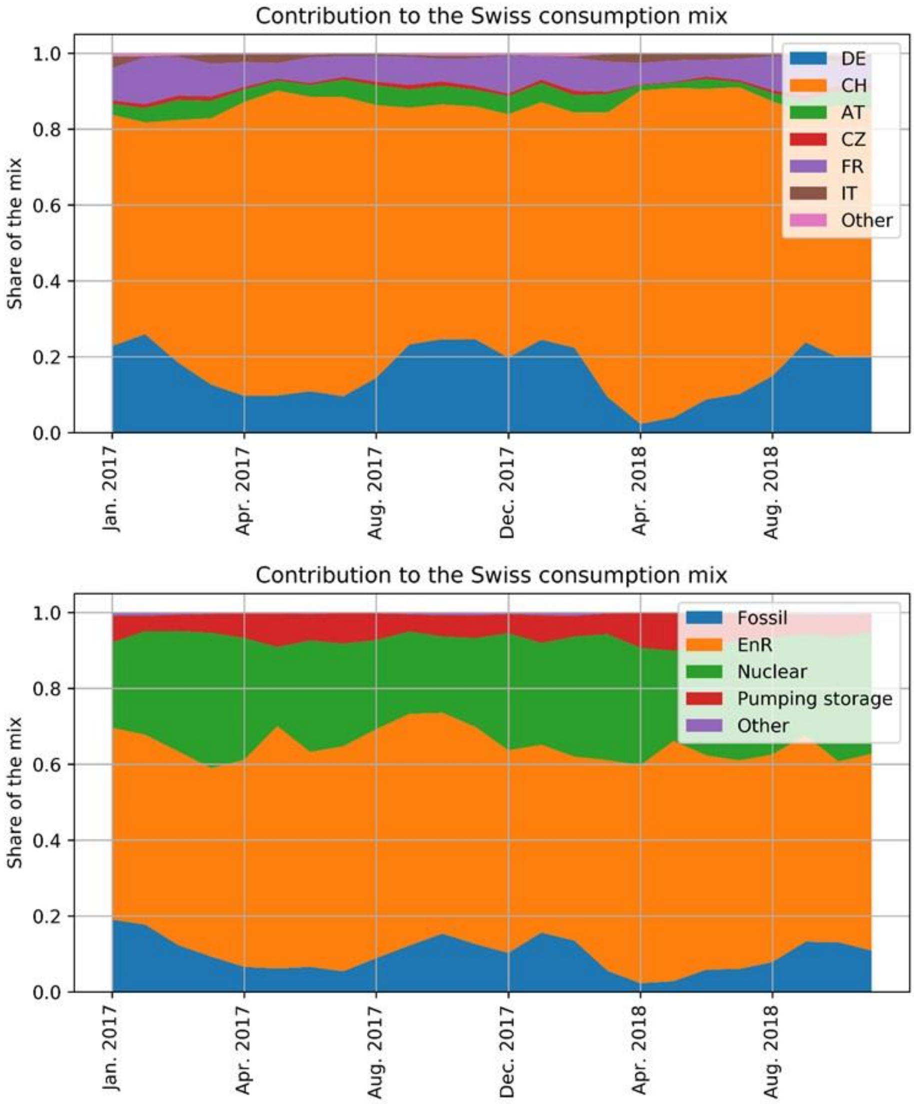


Figure 20: Contribution to the Swiss consumed electricity mix

The obtained shares of production means from each country to offer electricity to Swiss consumers has then to be multiplied by their respective environmental impacts. The impacts for all production means is calculated, with Simapro v7.4, based on ecoinvent V3.4 database. For calculating the hourly Swiss electricity supply mix, the pumping storage (STEP) is modelled using the environmental impact of the ecoinvent v3.4 dataset for the electricity produced by a pumping storage unit[25].

Nevertheless, the main source of data for electricity production at different time steps (i.e. ENTSO-E) and the chosen sources of data for the environmental assessment (i.e. ecoinvent) do not describe the energy production means with the same level of details. For example, ENTSO-E only mention “nuclear electricity” while ecoinvent will have both pressurized and boiling water reactor technologies (PWR, BWR). This discrepancy in the description of the model’s components brings an issue since impacts of energy sources must fit with the description of energy production means. A mapping file was thus built to connect these two sources of information for every relevant country, energy sources and technologies. Thus, for example, an aggregated value between the PWR and BWR is developed to have the “nuclear electricity” production mean as considered in ENTSO-E.

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[25] The used approach is a simplified one for modelling the pumping storage (STEP) flows. Indeed, it could also be possible to apply different impacts when the STEP is charged and conversely when it is discharged. But this modelling approach was not within the scope of the EcoDynBat project.

The necessity of using ENTSO-E data in the EcoDynBat project requires to aggregate data from ecoinvent. It is thus essential to find a ratio of each technology in ecoinvent to describe the energy sector in ENTSO-E. This information was found in the ecoinvent database since the shares of each technology are provided for the average annual electricity production datasets in 2014. Using these values is a simplification because market shares of different technologies have changed, but such changes are expected to have very small effects on the impacts of a sector.

Based on the environmental impacts per production means for each considered countries and the shares of production means at each time step, the hourly environmental impact of the Swiss consumed electricity can then be obtained for the years 2017 and 2018. The results presented in the Figure 21 illustrate the output of the developed EcoDynBat project for the GHG emissions and the Climate change impact category.

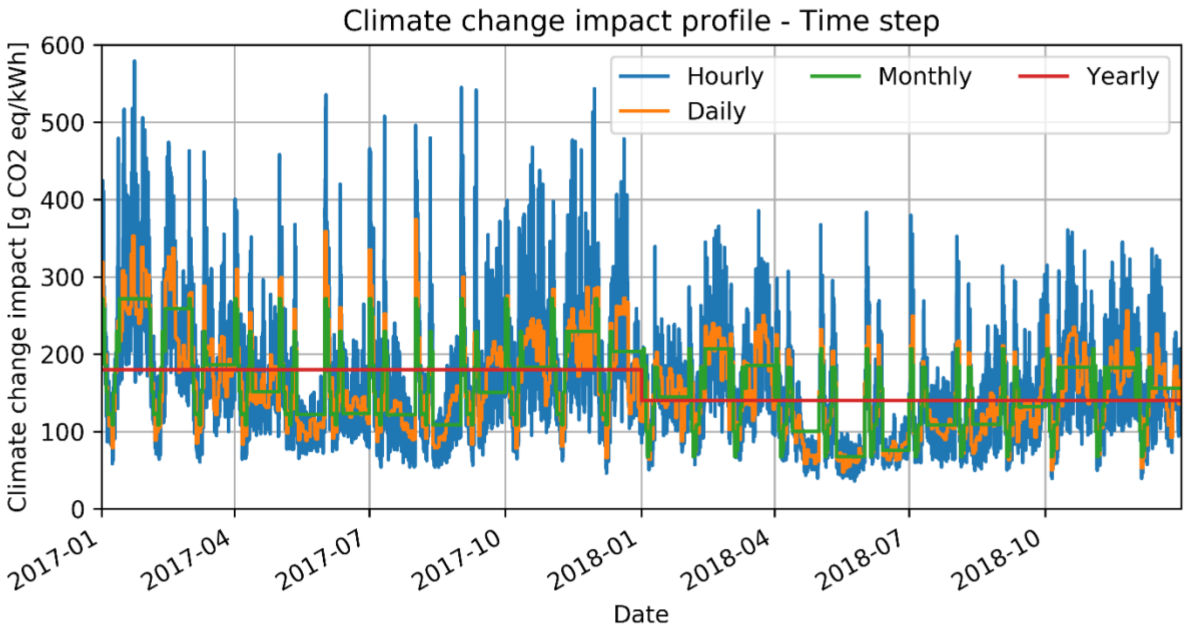

Figure 21: Climate change impact profile for the Swiss consumed electricity, according to various intra-annual time steps

Remark:
It is worth to mention that in the Swiss EcoDyynBat project, the ENTSO-E data have been collected for all the European countries and the developed method, based on a matrix-based computational approach can easily be applied to calculate the hourly electricty mix for other European countries using a physical approach for the cross-border exchanges.

Concerning the national electricity mix, challenges still remain to use a time-differentiated mix. In the EcoDynBat approach, empirical data from the past years (2017 and 2018) are used to derive the supply mix for different time series. It is a limitation, as from one year to another, fluctuations can happen due to the severity of the climate in winter, the decision to turn on or off production means in a country.

3) Use of the different LCA data (different time step from hourly to annual) in LCA of the energy use in Swiss buildings

The current supply mix is already usable to assess whether the time step influence the LCA of the building electricty demand and if yes for which use(s) and for which typology (office, residential...). First answers to these questions are provided in section 1.3.3 Switzerland part, application 2 with the LCA results of a building case study with different scenarios of energy systems.

The EcoDynbat datasets can also support the anaysis of load shiting and demand side management case studies using hourly GHG emissions as a decision criterion. However, such case studies are not reported in this report.

ELCAB project

The ELCAB research project (**E**lectricity in **L**ife **C**ycle **A**ssessments of **B**uildings) funded by the Swiss Federal Office of Energy (SFOE) from 2018 to 2020 assessed the effect of different electricity mixes, including an hourly mix on the environmental impacts of the electricity consumed by residential and office buildings. The approach chosen is described in Section **Error! Reference source not found.**. The main differences in modelling compared to the EcoDynBat project are the following:

- ELCAB uses commercial trade not physical trade data published by the ENTSO-E transparency platform.
- Commercial exports from Switzerland to neighbouring country are modelled with the Swiss production mix and subtracted from the total production before adding commercial imports.
- Imports to neighbouring countries are disregarded in ELCAB because it is assumed that electricity is hardly purchased from far distant power plants.

The following mixes were modelled:

1. Annual and seasonal attributional electricity mixes of Switzerland in 2018 and of a residential and a commercial building.
2. The Swiss consumer mix based on guarantees of origin 2018, the Swiss supply mix based on guarantees of origin 2018 and the ewz electricity mix based on guarantees of origin 2017.
3. The average future electricity mix of Switzerland
4. The long term marginal electricity mix of Switzerland and of ewz, the utility of the City of Zürich

The electricity mixes for these different load profiles are shown in Figure 22, Figure 23 and Figure 24. The electricity mixes derived from hourly production profiles and (economic) trade are rather similar and do not differ substantially from the annual national mix derived from hourly production profiles and (economic) trade. Their shares of nuclear electricity is about 40 %, hydro power contributes about 35 %, new renewables up to 10 % and fossil based electricity about 10 %.

The load profile of the office building leads to an annual electricity mix with slightly higher shares of hydroelectric power and PV electricity mainly at the expense of nuclear power.

The Swiss electricity mixes based on guarantees of origin show substantially higher shares of hydroelectric power and substantially lower shares of nuclear and fossil power. About one fourth of the electricity supplied to Swiss consumers is based on non renewable energies. If the electricity products based on renewable energies sold separately are excluded from the consumer mix, the share of electricity based on non renewable energies is about one third. More than 90 % of the ewz supply mix is produced with renewable energies, mainly in hydroelectric power plants.

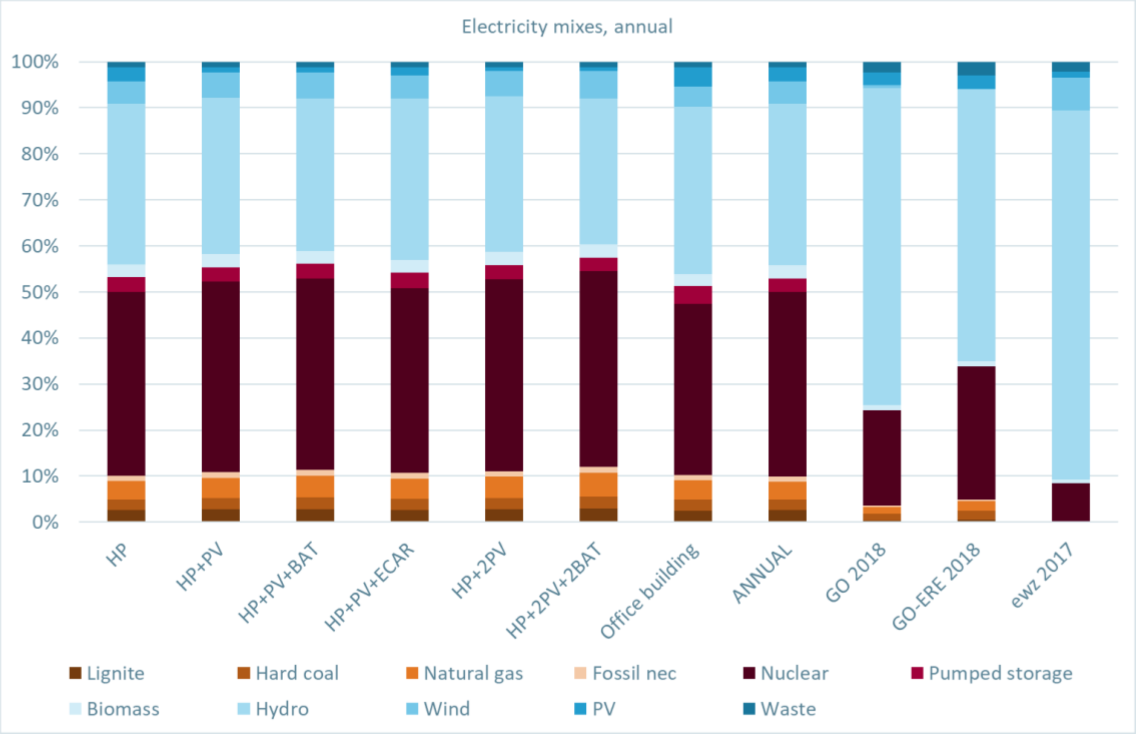

Figure 22: Technology shares of the annual Swiss electricity mixes for the different load profiles of the residential building Rautistrasse, the load profile of the ARE office building, the annual Swiss electricity mix (national load profile) and the Swiss consumer electricity mix 2018 according to guarantees of origin;
ANNUAL: Swiss annual mix (national load profile); GO 2018: Swiss consumer mix 2018 based on guarantees of origin;
GO-ERE 2018: Swiss supply mix 2018 (excluding electricity products based on renewable energy sold separately);
ewz 2017: supply mix of the utility of the city of Zürich.
Building specific electricity mixes matching hourly production and trade with the electricity consumption profile of the building, equipped with:
HP: heat pump for space heating and hot water; HP+PV: incl. 32 kWp PV system; HP+PV+BAT: including 32 kWp PV system and 32 kWh battery system; HP+PV+ECAR: including 32 kWp PV system and 7 electric car charging stations; HP+2PV: incl. 64 kWp PV system; HP+2PV+2BAT: incl. 64 kWp PV system and 64 kWh battery system;

The Swiss seasonal mixes exhibit moderate differences compared to the annual mixes. The Swiss winter mixes derived from the load profiles of residential and office buildings exhibit somewhat higher shares of nuclear and fossil based electricity (predominantly from Germany). Their profiles are all very similar. Thus there is only little variation. The Swiss summer mixes consists of less nuclear and less fossil based power plants. They show a somewhat higher dependency on the load profiles of the buildings. It is particularly interesting to note that the installation of on site PV systems leads to electricity mixes with a zero share of PV in the electricity mixes delivered from the grid.

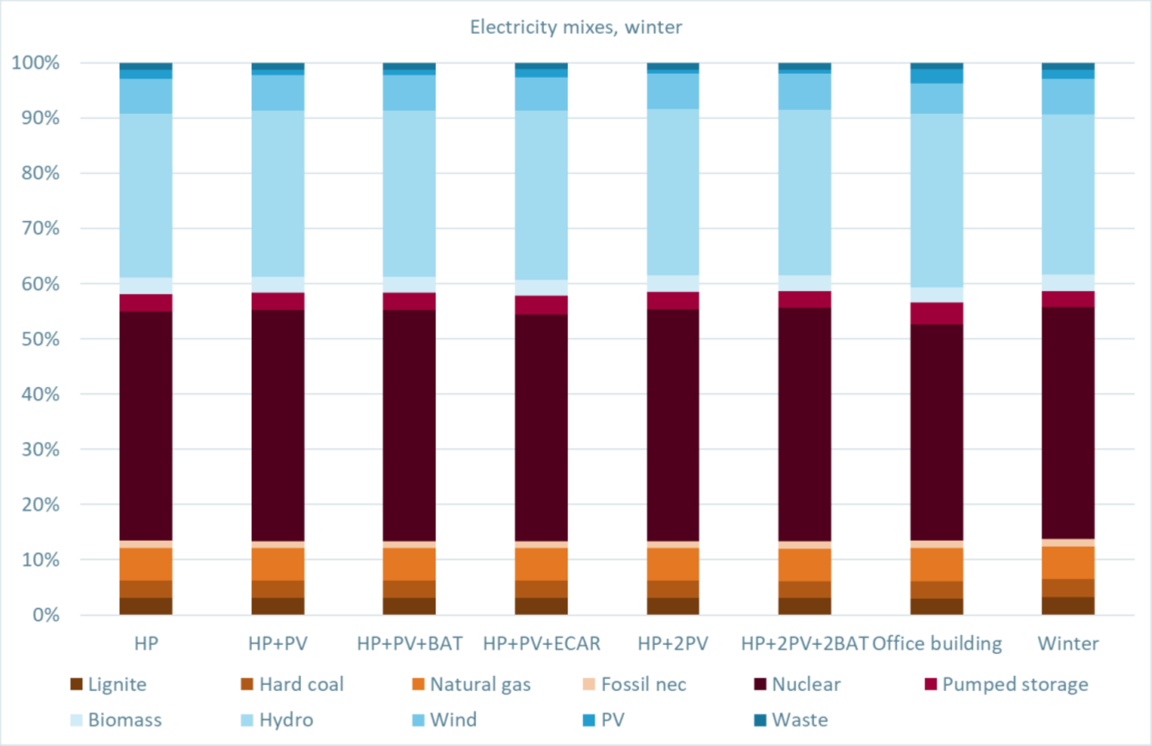

Figure 23: Technology shares of the winter Swiss electricity mixes for the load profiles of the residential building Rautistrasse, the ARE office building and the plain winter Swiss electricity mix (national load profile); Residential building equipped with: HP: heat pump for space heating and hot water; HP+PV: incl. 32 kWp PV system; HP+PV+BAT: including 32 kWp PV system and 32 kWh battery system; HP+PV+ECAR: including 32 kWp PV system and 7 electric car charging stations; HP+2PV: incl. 64 kWp PV system; HP+2PV+2BAT: incl. 64 kWp PV system and 64 kWh battery system; Winter: Swiss winter mix (national load profile).

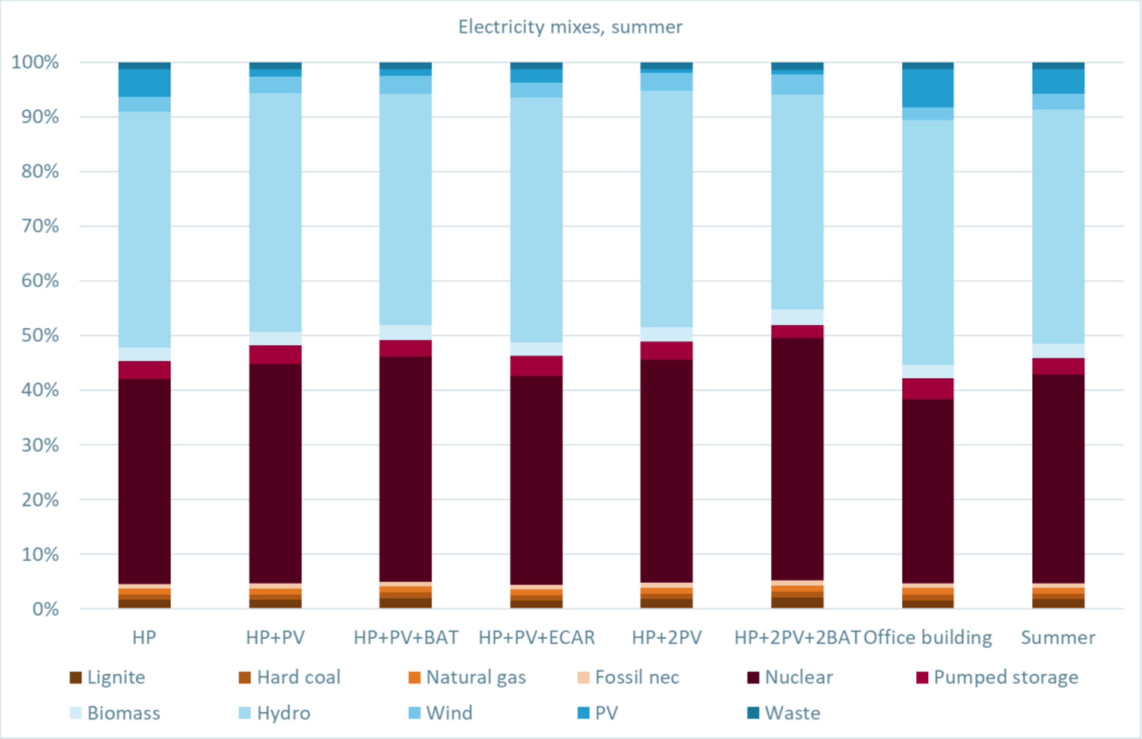

Figure 24: Technology shares of the summer Swiss electricity mixes for the load profiles of the residential building Rautistrasse, the ARE office building and the plain summer Swiss electricity mix (national load profile); Residential building equipped with: HP: heat pump for space heating and hot water; HP+PV: incl. 32 kWp PV system; HP+PV+BAT: including 32 kWp PV system and 32 kWh battery system; HP+PV+ECAR: including 32 kWp PV system and 7 electric car charging stations; HP+2PV: incl. 64 kWp PV system; HP+2PV+2BAT: incl. 64 kWp PV system and 64 kWh battery system; Summer: Swiss summer mix (national load profile).

The annual future Swiss electricity mix according to the Scenario “New Energy Policy”, Variant C&E will shift from nuclear power to substantially more power from renewable sources (see Figure 25). One part of the reduction in production volumes from nuclear power plants will be compensated by natural gas fired power plants. They reach a share of up to 16 % in 2035 and then drop to about 6 % in 2050. PV production will increase from a share of below 1 % to 15 % in 2050. Geothermal power reaches 6 % in 2050, wind power slightly less.

The 2020 future electricity mix generally shows more similarities to the annual electricity mix derived from annual production and (economic) trade data. The shares of new renewable energies and fossil based power in the 2018 electricity mix are higher and the share of pumped storage is smaller than in the Prognos electricity mix 2020. These seven electricity mixes are used to establish an average electricity mix for 2020 to 2050, i.e. the first half of the 60 years amortisation period of buildings. The average future electricity mix includes nearly 50 % hydroelectric power, 15 % nuclear power, 8 % produced with natural gas and 7 % PV electricity.

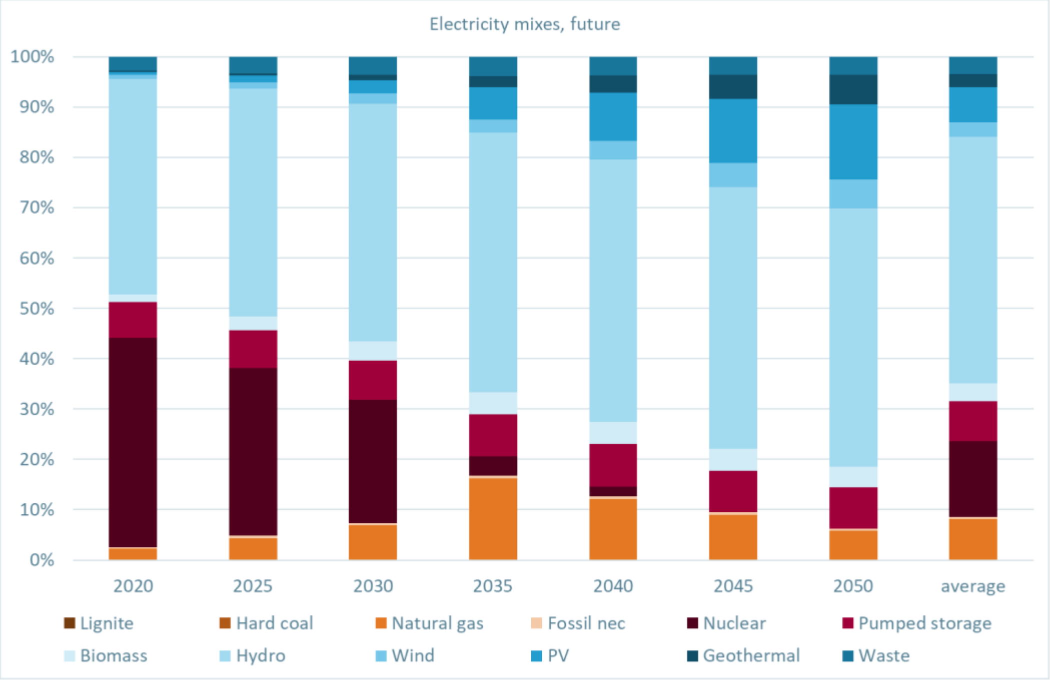

Figure 25: Technology shares of annual future Swiss electricity mixes from 2020 to 2050 according to Prognos (2012) and for the average electricity mix 2020 to 2050

The specific greenhouse gas emissions of the Swiss national electricity mix 2018 vary between 55 g CO_2-eq/kWh (Swiss consumer mix), 70 g CO_2-eq/kWh (Swiss supply mix) and nearly 130 g CO_2-eq/kWh (physical production and commercial trade covering the national load profile 2018, see Figure 26). Imports of electricity generated with fossil fuels (lignite, hard coal and natural gas) contribute up to three quarters of the total emissions.

The ewz 2017 electricity mix causes less than 20 g CO_2-eq/kWh which is mainly due to the fossil free electricity mix. The long term marginal electricity mix (100 % natural gas fired gas combined cycle) emits more than 450 g CO_2-eq/kWh.

The greenhouse gas emissions of the annual Swiss electricity mix, modelled according to the New Energy Policy (NEP) scenario of the Swiss energy strategy 2050 (see Subchapter **Error! Reference source not found.**), increase from less than 40 g CO_2-eq/kWh in 2020 to nearly 120 g CO_2-eq/kWh 2035. After that, they drop again to about 60 g CO_2-eq/kWh. On average 73 g CO_2-eq/kWh are emitted from 2020 to 2050. The emissions in 2020 are distinctly lower than those of the electricity mix 2018 based physical production plus commercial trade, because the future electricity mixes disregards trade.

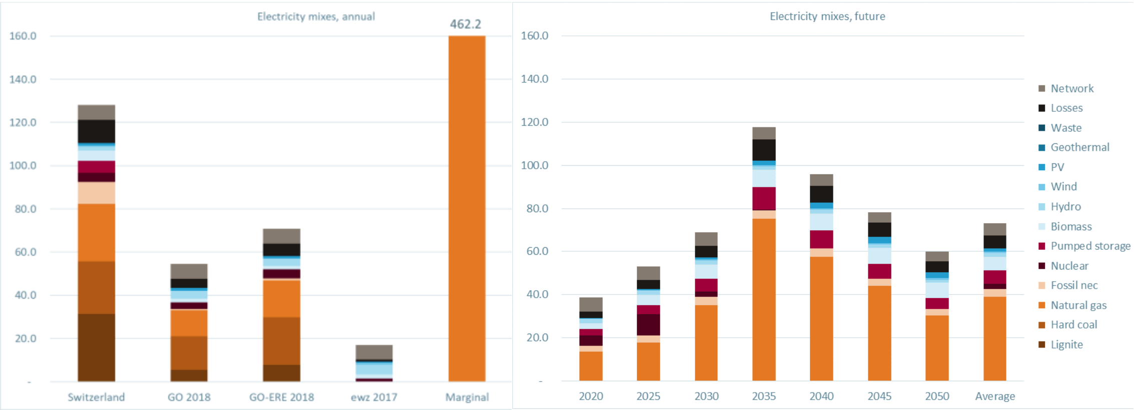

Figure 26: Greenhouse gas emissions in g CO_2-eq/kWh low voltage of the annual Swiss electricity mix (national load profile, Switzerland), the Swiss consumer mix (GO 2018), the Swiss supply mix (GO-ERE 2018, excluding electricity products based on renewable energy sold separately), the ewz electricity mix 2017 based on guarantees of origins, the long term marginal electricity (Switzerland and ewz), and the average future electricity mix Switzerland 2020-2050 (based on the New Energy Policy (NEP) scenario).

The specific greenhouse gas emissions of electricity supplied to the residential building “Rautistrasse” amount to between nearly 130 g CO_2-eq/kWh and nearly 150 g CO_2-eq/kWh (see Figure 27). Imports of fossil based electricity are the main cause.

The specific greenhouse gas emissions of the base case (HP), i.e. excluding any self generated electricity nor on site storage, are nearly identical to the specific greenhouse gas emissions of the Swiss electricity mix (physical production and commercial trade matching the national load profile). This is not surprising because the electricity mixes are very similar too (see Figure 22).

Self generation of electricity with PV and storage of this electricity in stationary batteries leads to higher specific greenhouse gas emissions of the remaining electricity supplied from the grid. For instance, PV electricity from the building displaces PV electricity in the mix supplied to the building (compare the colums “HP” and “HP+PV”).

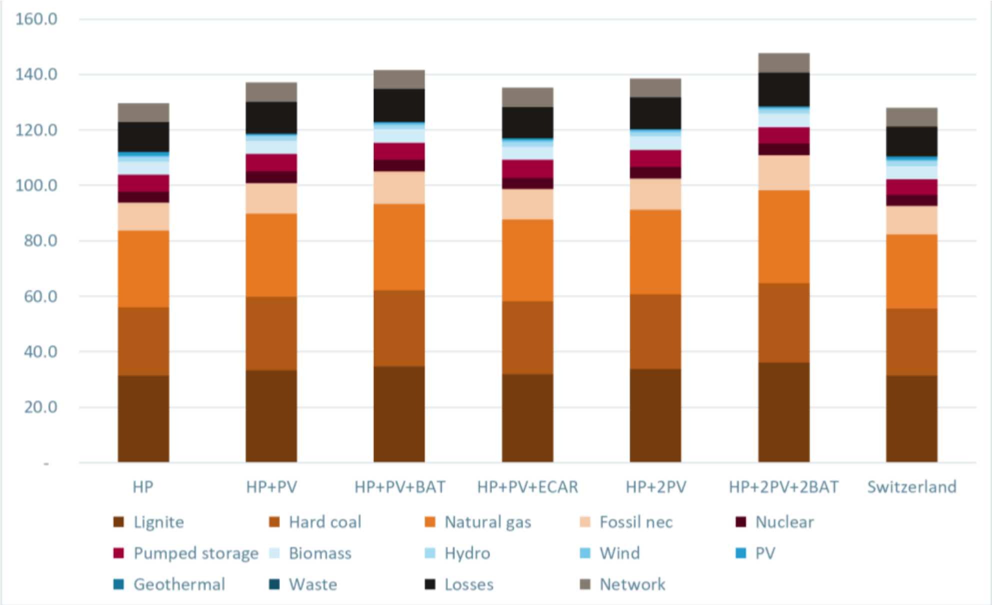

Figure 27: Greenhouse gas emissions in g CO_2-eq/kWh low voltage of the annual electricity mixes of the load profiles of the residential building and of Switzerland;
Residential building equipped with: HP: heat pump for space heating and hot water; HP+PV: incl. 32 kWp PV system; HP+PV+BAT: including 32 kWp PV system and 32 kWh battery system; HP+PV+ECAR: including 32 kWp PV system and 7 electric car charging stations; HP+2PV: incl. 64 kWp PV system; HP+2PV+2BAT: incl. 64 kWp PV system and 64 kWh battery system; Switzerland: Swiss annual mix (national load profile).

The specific greenhouse gas emissions of the seasonal (summer and winter, respectively) electricity mixes of the residential building and of the Swiss electricity mix based on physical production and commercial trade differ considerably: in summer (April to September) the greenhouse gas emissions vary between 70 and 78 g CO_2-eq/kWh whereas in winter (October to March) they amount to between 164 and 169 g CO_2-eq/kWh (see Figure 28). One kWh consumed in the winter period causes more greenhouse gas emissions than 2 kWh consumed during the summer period. The influence of self generation and storage of electricity on the specific greenhouse gas emissions of the remaining electricity supplied to the building is more pronounced during the summer than the winter period.

The specific greenhouse gas emissions of the remaining electricity supplied to the building decrease both in the summer and winter period. This seems to be contradictory to the effect of self generation and storage on the specific greenhouse gas emissions of the remaining electricity supplied the building on an annual basis. However, the share of winter period electricity (with higher specific greenhouse gas emissions) is higher in cases with self production and storage, which leads to the observed increase in specific greenhouse gas emissions of the electricity mix supplied to the building on an annual basis.

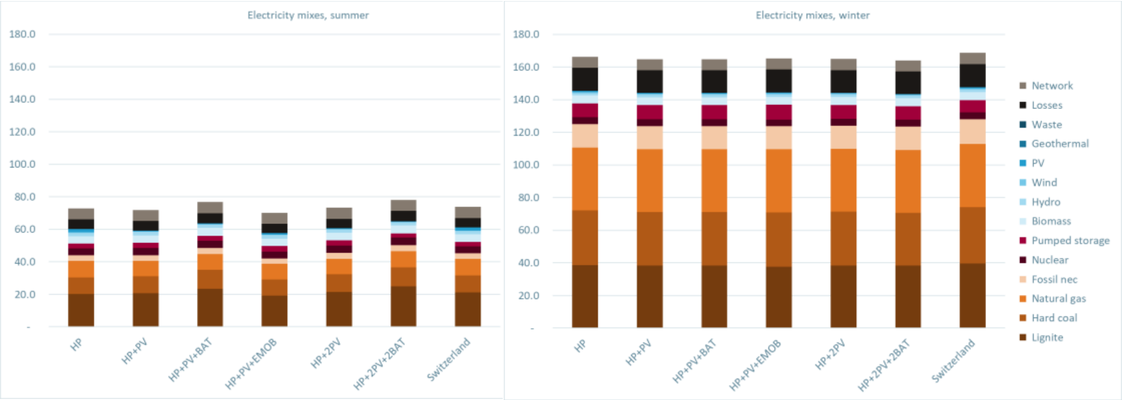

Figure 28: Greenhouse gas emissions in g CO_2-eq/kWh low voltage of the seasonal electricity mixes of the load profiles of the residential building and of Switzerland;
Residential building equipped with: HP: heat pump for space heating and hot water; HP+PV: incl. 32 kWp PV system; HP+PV+BAT: including 32 kWp PV system and 32 kWh battery system; HP+PV+ECAR: including 32 kWp PV system and 7 electric car charging stations; HP+2PV: incl. 64 kWp PV system; HP+2PV+2BAT: incl. 64 kWp PV system and 64 kWh battery system; Switzerland: Swiss seasonal mix (national load profile).

Sweden

Hourly data on production, imports and exports in Sweden is available from ENTSO-E and Svenska Kraftnät (European Network of Transmission System Operators, 2020; Svenska kraftnät, 2020). Previous projects have investigated the time resolution of the electricity mix on the Nordic electricity market. In developing the Tidstegen method, Gode et al. (2015) concluded that this aspect does not matter in the short term in consequential LCA, but that it might matter in the long term, depending on how electricity demand and supply evolve. Therefore, they base their long-term assessments on a breakdown of electricity demand depending on the year, season and time of day (daytime or nighttime).

Erlandsson et al. (2018) concluded that time resolution of the electricity mix did not significantly influence the results when using an average mix for the LCA of a case study building. However, they concluded that time resolution can matter when using a marginal electricity mix, depending on the method used to select the electricity mix. For instance, when selecting the top 10% of the merit order as the marginal mix, and when considering a scenario for the Nordic mix in 2050, the marginal emission factor showed a high hourly variability. This could prove important e.g. when carrying out a consequential LCA related to the choice of heating solution (e.g. electric heating or district heating).

Apilot version of the NollCO₂ certification system also required an assessment of the impact of energy demand based on hourly values for supply and demand. However, the more recent pilot version uses yearly electricity emission factors instead.

Norway

Hourly data on production, consumption and exchange in Norway is available from ENTSO-E and Nordpool (2020). Norway has several physical links to the European electricity grid. But these links are bottlenecked, so that the maximum import/export capacity is approx. 6,000 MW (and growing as new connection lines are added). In comparison, the total production capacity of Norway is about 31 000 MW. Figure 29 , shows the hourly Production, Exchange and Consumption in Norway from 2013 to 2019.

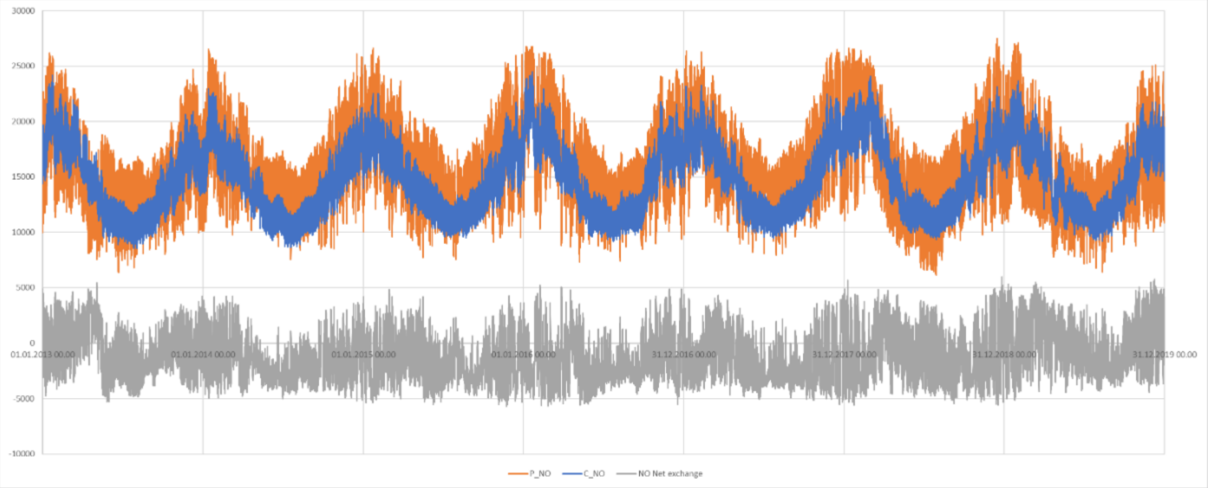

Figure 29: Electricety Production, Exchange and Consumptionn in Norway 2013 to 2919 (MWh/h)

As the figures shows, Norway is importing during winter and early spring, and are exporting late spring, summer, and autumn. The figure also shows that Norway on average is a net exporter of electricity.
The hourly mix of the Norwegian production is totally dominated by hydropower (>95%), with small contribution from wind (~2,5 %) and thermal (~2,5 %).

B.6 Marginal electricity mix (electricity mix(es) applicable in consequential LCAs)

Denmark

No dataset available.

France

In order to identify the short term marginal mix, the different production techniques are ranked using a "merit order". Technologies that cannot be adjusted according to the demand (e.g. wind or PV, that depend on the weather) are at the bottom of this ranking. Adjustable technologies with the lowest constraints and the highest cost are at the top. Two methods have been implemented in the EQUER tool:

- the Greenhouse Gas Protocol method (WBCSD & WRI 2007), considering a marginal mix corresponding to the 10% top ranked productions.
- a more physical 2 steps model, evaluating the mix with and without the studied building, using a model representing the electric system as presented in § 1.6.5 (Roux et al. 2016a). The marginal electricity mix can be defined for past years (historical mix) or for a long term period using energy transition scenarios, leading to a long term marginal approach.

Hungary

In Hungary, the marginal mix consist of natural gas power plants. No detailed assessment has been carried out.

Switzerland

There is no official, national model of a consequential LCA of electricity.

Two different concepts of establishing a consequential electricity mix are proposed (see also Frischknecht 2016). The consequential annual national electricity mix of Switzerland is derived from 1) energy policy scenarios and 2) based on a thinking model.

Ad 1: The consequential (long term marginal) electricity mix is established as the difference in technology specific power production in the future (e.g. in 2050) according to two (distinctly) different scenarios (e.g. business as usual and new energy policy according to the national energy scenarios, Prognos 2012). The procedure is illustrated using the Swiss case (see Table 12). The difference in electricity production and consumption in Switzerland in 2050 is about 8 TWh per year, strongly depending on which of the energy scenarios is likely to happen or be implemented. The additional electricity consumption of the Business As Usual scenario BAU compared to the most ambitious New Energy Policy scenario NEP will be covered with electricity from fossil power plants, mainly natural gas fired power plants. Natural gas will also be used to step in for the new renewables which are assumed to produce much less in the BAU compared to the NEP scenario. Hence, the long term marginal electricity mix of Switzerland is likely to be composed of 100 % natural gas fired gas combined cycle power plants, similar to the situation in Hungary.

Table 12: Power plant technologies in Switzerland in 2009, in 2050 according to three different policy scenarios as well as the difference in production in the BAU and NEP scenario; (Prognos 2012); specific greenhouse gas emissions and non renewable primary energy demand

Technology	**Production mix 2009 [TWh]**	**Business As Usual BAU 2050 [TWh]**	**New Energy Policy NEP 2050 [TWh]**	**Political Measures POM 2050 [TWh]**	**longterm marginal mix: BAU minus NEP [TWh]**
Hydroelectric power	37.14	41.58	44.15	44.15	-2.57
New renewables	0.91	8.96	22.59	22.59	-13.63
Nuclear power	26.12	0.00	0.00	0.00	0
Fossil Power plants	0.36	29.51	4.67	2.12	24.84
Waste	1.97	2.28	2.96	2.96	-0.68
Imports	0.00	0.00	0.00	7.2	0
Total	66.49	82.33	74.37	79.02	7.96
Climate change impact [g CO_2-eq/kWh]	**30**	**213**	**76**	**61**	**466**
primary energy demand, non renewable [kWh oil-eq/kWh]	**2.7**	**0.96**	**0.28**	**0.29**	**8.0**

Ad 2: The following thinking model is applied to derive a consequential electricity mix: Each kWh electricity (produced with renewable energies, mainly with hydroelectric power plants) which is not consumed in Switzerland, is exported to Europe and is an offer to the European utilities to shut down (and dismantle) power plants which run on fossil or fissile fuels, i.e. lignite, hard coal, fuel oil, natural gas and nuclear power plants. In a project for IEA PVPS, different European non-renewable power mixes were established (Frischknecht et al. 2015, see Table 13). It shows that the European non-renewable power mix is likely to change in future depending on the policy scenario. Because decisions on building alternatives are taken as from today, we recommend to use the present (2009) European non-renewable electricity mix.

Table 13: European non renewable electricity mix today (2009) and in 2050 (three scenarios, based on NEEDS 2008, NEEDS 2009); specific greenhouse gas emissions and non renewable primary energy demand;
nd: not determined

Technology	2009	BAU 2050	REAL 2050	OPT 2050
Hard coal	21.4%	34.2%	8.1%	14.9%
Lignite	26.4%	12.5%	0.0%	0.0%
Heavy fuel oil	1.6%	0.8%	0.3%	0.0%
Natural gas	14.9%	24.0%	57.7%	85.0%
Nuclear power	34.1%	28.5%	33.9%	0.0%
Total	100.0%	100.0%	100.0%	100.0%
Climate change impact [g CO_2-eq/kWh]	**763**	**nd**	**nd**	**nd**
primary energy demand, non renewable [kWh oil-eq/kWh]	**3.81**	**nd**	**nd**	**nd**

Sweden

Two notable reports have investigated the use of marginal electricity mixes in building LCA in the past few years, but neither method is commonly used in practical LCAs.

Gode et al. (2015) developed marginal mixes for electricity and heating for the Tidstegen method, addressing both what they called dynamics (i.e. long-term changes in the energy mix) and time resolution (i.e. differences between different seasons or times of day). For electricity, the marginal mix in the coming 5-15 years is assumed to be fully composed of fossil fuel-based electricity imported primarily from Denmark and Germany. The justification is that hydropower is used to regulate seasonal and hourly changes in electricity demand, but the amount of hydropower used in a year is limited by weather conditions. In other words, all hydropower capacity will always be used within a year; an increase in demand thus cannot be met by an increase in hydropower production and has to be met with imported electricity produced in thermal power plants.

In the long term, the marginal mix in the Tidstegen method depends on the choice of future scenario. Three future scenarios are proposed (reference, low greenhouse gas emissions and high greenhouse gas emissions). In each scenario, different technologies are used to meet a marginal increase in electricity demand depending on when this additional demand happens (season, time of day). When assessing a measure that would change the building’s energy demand, this change in demand is broken down into different marginal mixes depending on when the change in demand happens. Each marginal mix takes into account short-term effects from this change in demand (e.g. changes in how plants are operated) as well as long-term effects (e.g. changes in investments and installed capacity for various technologies on the grid). For instance, a measure reducing energy demand from appliances during the night will use the nighttime emission factors, whereas the installation of on-site PV panels will mostly use the daytime emission factor for summer, and to some extent spring and autumn, but will barely use the emission factor for winter. Each measure is assessed in each of the three future scenarios, and a measure is said to have positive (resp. negative) effects if its effects are positive (resp. negative) in most scenarios.

Another report developed present and future marginal emission factors for the Nordic electricity market, with a hourly time resolution (Erlandsson et al., 2018). The hourly data was based on the ENTSO-E database (European Network of Transmission System Operators, 2020). The future scenario was based on the “Nordic Energy Technology Perspectives” report (International Energy Agency, 2016). The influence of different ways of choosing the marginal emission factor was investigated. Three short term marginal emission factors were developed for each hour of a reference year (present) and a future year (2050):

- A factor where the marginal mix is defined as the top 10% technologies in the merit order, including imports, according to the Greenhouse Gas Protocol method (WBCSD & WRI 2007).
- A factor where the marginal mix is defined as all load-following technologies including imports, i.e. all technologies that can be used to meet a short-term change in demand.
- A factor considering substitution effects. Imports are considered as above. Exports are assumed to displace a similar technology in another country, and have “negative emission factors”.

This report was an initial attempt at exploring different methodological choices and their implications when applied to the assessment of a case study building. It has not been developed into a method that is commonly used in LCA.

Finally, the draft version of the NollCO_2 certification system uses a marginal approach to determine benefits from locally produced electricity exported to the grid. The approach is based on the GHG Protocol guidelines (WBCSD & WRI 2007). Long-term marginal effects are neglected, because each installation for on-site power production is assumed to be too small to significantly affect installed capacity for other production technologies on the grid. Regarding short-term marginal effects, on-site electricity exported to the grid is assumed to always lead to a reduction in electricity production in coal power plants. This assumption is based on two observations: First, the price of operating coal power plants is high, and it is not profitable to operate coal power plants when renewable electricity is available. Second, regardless of the time of year, there are always coal power plants being operated in neighboring countries (whose production could therefore be reduced if additional renewable power was added to the grid). This approach is only applied to calculate benefits from on-site electricity produced in excess of the building’s needs. Greenhouse gas emissions from electricity used in the building are calculated using an emission factor for the average supply mix.

Annex C: Example modelling choices made in different tools

In this annex, the modelling possibilities are summarized below. Example choices in different tools and countries are pesented.

A) Electricity mix modeling possibilities
1. Generic or provider specific electricity mix
2. General mix: Regional, national or continental scale
3. Production mix, supply mix
4. Physical flows, contracts, guarantee of origin combined with physical production, or guarantee of origin only
5. Mix corresponding to production + import, production – export + import (possibly according to guarantee of origin), national electricity declaration
6. Gross or net trade balance
7. mix based upon empirical data from Transmission System Operator (TSO), data derived from/determined with a model (e.g., statistical model…) or other data
8. Universal electricity mix or use-specific electricity mix (heating, cooling, lighting, hot water…)
9. Historical, present or future mix (e.g. average present-2050)
10. Average or marginal mix
11. Annual, seasonal or hourly mix
12. Allocation approach for electricity produced on site (photovoltaics, but also wind) exported to the grid

    i. product and construction stage (“module A”): only self-consumed part of environmental impacts of the entire PV plant is accounted for, and attributed to the self-consumed part,

    ii. product and construction stage: environmental impacts of the entire PV plant is accounted for; use stage: environmental impacts of PV electricity is accounted for the electricity exported and subtracted from the use stage environmental impacts (Swiss method, according to SIA 2040), no environmental impacts on self consumed PV electricity (already accounted for in product and construction stage of the building); same result like approach i) above);

    iii. product and construction stage: environmental impacts of the entire PV plant is accounted for; use stage: exported electricity gives rise for avoided impacts according to the amount of electricity exported and the technology (mix) assumed to be replaced (French methods EQUER and E+C-).

B) Example choices
Each tool is presented in a table explaining the choices and intentions. Then a table is given in order to prepare a synthesis including all participating countries (see next table).

Template to be used by Annex 72 partners						
	Criterion	**Insert your country:………………………** Type of approach (e.g., commonly used approach (labelling systems), research assessment/study)				
1	**Generic or specific**	provider specific	generic			
2	**Geographic scope**	continental	regional	national		
	Electricity mix model					

3	**Type of mix**	(1) Production mix	(2) Supply mix			
4	**Nature of trade flows**	Physical flows	Flows based on contracts	Flows based on Guarantee of Origin (GO) purchase together with physical production	Flows based on Guarantee of Origin (GO)	
5	**Modelling choice for the supply mix**	(1) Production + imports	(2) Production – exports + imports	(3) Production – Δ exports + Δ imports *NB: contemporaneous physical imports and exports are considered transit trade and thus balanced. Only net import and net export volumes (determined on an hourly or 15 min basis) are taken into account*	(4) According to national electricity declaration *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*	(5) Production minus Exports (Production volume – domestic GO supply volume, per technology) plus Imports (foreign GO supply volume, per technology) *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*
6	**Balance of import/export at each border with the studied country and each neighbouring country**	Gross balance	Net balance	Not applicable		
7	**Data types for the energy carrier flows**	Direct use of empirical data from Transmission System Operator (TSO)	Data derived from/determined with a model (e.g., statistical models…)	Other data (e.g., use of national statistics different from TSO data, literature data)		
8	**End uses dependence 1)** (heating, lighting, cooling, etc.)	universal mix	use specific mix			
9	**Time dimension**	historical mix	present mix	future mix		
10	**LCA modelling approach**	average mix	marginal mix			
11	**Time granularity**	annual average mix	seasonally differentiated mix	hourly differentiated mix		
12	**Allocation of in site PV electricity production**	Impacts of self consumed part only	Gross impacts minus PV impacts of fed in electricity	Gross impacts minus grid mix impacts of fed in electricity		

[1]): The mix (universal or use specific) may be defined on the level of annual, seasonal, daily, hourly or 15 minutes' averages. Combining hourly (or 15 minutes) universal mixes with the use profiles of heating, lighting, cooling or ventilation) and integrating them to annual values will result in annual use specific mixes.

C.1 Example for France

a) Mainstream assessment (E+C-, building regulation studied for 2020)

Choice	**Explanation / Intention**
Generic mix	The regulation is about the intrinsic quality of the building, not the choice of an electricity provider by the users
National mix	It is a national regulation the % of imported/exported electricity is low and is taken into account using a gross balance (production – exports + imports)
Consumer mix = supply mix (physical trade flows on a national level)	It corresponds to the impacts generated by buildings because of the strong interconnection among the grid.
Use-specific mix	Electric heating induces a peak load and higher CO2 emissions in winter, whereas e.g. domestic hot water is produced in the night and stored in tanks. Different CO2 emissions per kWh are therefore considered according to each use, but this is not really science based. It is rather the result of a negociation between e.g. gas and electricity lobbies.
Present or future mix ?	In the first version E+C-, the present mix is considered, empirical data from TSO are used. But the electricity lobby insists towards using a future mix, which would be more favourable to electric heating. This would increase the electricity consumption, making more difficult to progress towards energy transition. The French law imposes an objective of reducing the nuclear % and increasing the renewables, but a new law is voted every 5 years postponing the date for this objective. Environmentalists advise therefore to keep the present mix by precaution because it is not sure if energy transition and impact reduction will be effective.
Average or marginal mix ?	It is not precisely defined in the use-specific mix (see above)
Annual mix	It has to be simple, and temporal variation is accounted for in the use-specificity
Allocation for exported PV	1/3 of avoided impacts : the renewable lobby wanted 100%, the electricity lobby 0% and the ministry in charge of dwellings has decided 33%.

b) Design or research assessment (Equer method)

Choice	**Explanation / Intention**
Provider specific mix if the purpose is to help in facility management, generic mix with a sensitivity study for 100% renewable in other cases	It is often useful to show the importance of users choices in the environmental performance of buildings, and the choice of an electricity provider has a large influence on environmental impacts. A cooperative gathering renewable electricity producers proposes 100% renewable electricity to clients, and it is therefore interesting to perform a sensitivity study comparing the generic and 100% renewable mixes.
National mix	The % of imported/exported electricity is low and is taken into account using a gross balance (production – exports + imports)
Consumer mix = supply mix (physical flow)	It corresponds to the impacts generated by buildings
Universal or Use-specific mix	Specific to all uses of the studied building, being tested in a hourly marginal mix method in a research project

Choice	**Explanation / Intention**
Present or Future mix	The present mix is considered at the moment (precautionary principle). Different scenarios are compared in the research project, due to the vague long term energy transition policy in France. Empirical data from TSO are used for the present mix, data derived from a model is used for future mixes
Average or marginal mix ?	The user can choose between both options but short term and long term marginal is advised in order to show consequences of choices. Two options are being compared in the research program : GHG Protocol (10% of merit order), or supplementary consumption of the studied building.
Hourly mix	It is more precise, and simple for the user because the calculation is automatic.
Allocation for exported PV	100% of avoided impacts because the exported electricity is really consumed, there is no overproduction at the moment. The method remains valid even if 0% self-consumption (case of a PV power plant).

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FRANCE

Criterion	**Insert your country: French method EQUER** Design and research tool				
Generic or specific	[✓ provider specific]	[✓ generic]			
Geographic scope	continental	regional	[✓ national]		
Electricity mix model					
Type of mix	(1) Production mix	[✓ (2) Supply mix]			
Nature of trade flows	[✓ Physical flows]	Flows based on contracts	Flows based on Guarantee of Origin (GO)		
Modelling choice for the supply mix	(1) Production + imports	[✓ (2) Production – exports + imports]	(3) Production – ∆ exports + ∆ imports *NB: contemporaneous physical imports and exports are considered transit trade and thus*	(4) According to national electricity declaration *NB: This model only works for countries*	(5) Production minus Exports (Production volume – domestic GO supply volume, per technology) plus Imports (foreign GO supply volume, per technology)

			balanced. Only net import and net export volumes (determined on an hourly or 15 min basis) are taken into account	*such as EU and EFTA countries where electricity disclosure is mandatory*	*NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*
Balance of import/export at each border with the studied country and each neighbouring country	Gross balance	Net balance	Not applicable		
Data types for the energy carrier flows	Direct use of empirical data from Transmission System Operator (TSO)	Data derived from/determined with a model (e.g., statistical models…)	Other data (e.g., use of national statistics different from TSO data, literature data)		
End uses dependence 1) (heating, lighting, cooling, etc.)	universal mix	use specific mix			
Time dimension	historical mix	present mix	future mix		
LCA modelling approach	average mix	marginal mix			
Time granularity	annual average mix	seasonally differentiated mix	hourly differentiated mix		
Allocation of in site PV electricity production	Impacts of self consumed part only	Gross impacts minus PV impacts of fed in electricity	Gross impacts minus grid mix impacts of fed in electricity		

1): The mix (universal or use specific) may be defined on the level of annual, seasonal, daily, hourly or 15 minutes' averages. Combining hourly (or 15 minutes) universal mixes with the use profiles of heating, lighting, cooling or ventilation) and integrating them to annual values will result in annual use specific mixes.

C.2 Example for Switzerland (a) and b) prepared by treeze Ltd., c) prepared by HES-SO)

a) Mainstream assessment (technical bulleting SIA 2040 « SIA energy efficiency path », SIA 2017)

Choice	**Explanation / Intention**
Generic mix	The technical bulletin is about assessing buildings in view of their compatibility with the intermediate goals of the 2000-Watt-society (EnergieSchweiz für Gemeinden et al. 2014b); Specific long-term contracts for renewable electricity supply may be accounted for (for max. 50 % of the electricity consumed by the building)
National mix	It is a national technical bulletin, imported/exported electricity is taken into account according to the guarantees of origin sold to Swiss consumers (Pronovo 2019).

Choice	**Explanation / Intention**
Consumer mix	See above
Generic mix	No differentiation between different use types (such as heating, cooling, ventilation, hot water etc.) ; electricity consumption of all uses are modelled with the same mix.
Present or future mix ?	The average present (recent past) electricity mix is applied.
Average or marginal mix ?	It is an average electricity mix, although in some communities/cities which rely on 100 renewable electricity, scenarios using marginal mixes have been evaluated (Frischknecht 2016).
Annual mix	The annual mix is being used to keep it simple and because no seasonal Swiss electricity mixes are available as of now but see EcoSynBat and ELCAB project descriptions.
Allocation for exported PV	Exported PV electricity has the environmental profile of PV mounted/integrated in the building under assessment. If 100 % of PV electricity is exported, the environmental impacts of PV power plant manufacture attributed to the building is zero.

SWITZERLAND					
Criterion	**Swiss case (SIA 2040:2017):** National approach used for building LCAs in the context of national labelling systems				
Generic or specific	provider specific	generic			
Geographic scope	continental	regional	national		
Electricity mix model					
Type of mix	(1) Production mix	(2) Supply mix			
Nature of trade flows	Physical flows	Flows based on contracts	Flows based on Guarantee of Origin (GO)		
Modelling choice for the supply mix	(1) Production + imports	(2) Production – exports + imports	(3) Production – Δ exports + Δ imports *NB: contemporaneous physical imports and exports are considered transit trade and thus balanced. Only net import and net export volumes (determined on an hourly or 15 min basis) are taken into account*	(4) According to national electricity declaration *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*	(5) Production minus Exports (Production volume – domestic GO supply volume, per technology) plus Imports (foreign GO supply volume, per technology) *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*
Balance of import/export at each border with the studied country and each neighbouring country	Gross balance	Net balance	Not applicable		

Data types for the energy carrier flows	Direct use of empirical data from Transmission System Operator (TSO)	Data derived from/determined with a model (e.g., statistical models…)	Other data (e.g., use of national statistics different from TSO data, literature data)
End uses dependence 1) (heating, lighting, cooling, etc.)	universal mix	use specific mix	
Time dimension	historical mix	present mix	future mix
LCA modelling approach	average mix	marginal mix	
Time granularity	annual average mix	seasonally differentiated mix	hourly differentiated mix
Allocation of in site PV electricity production	Impacts of self consumed part only	Gross impacts minus PV impacts of fed in electricity	Gross impacts minus grid mix impacts of fed in electricity

1): The mix (universal or use specific) may be defined on the level of annual, seasonal, daily, hourly or 15 minutes' averages. Combining hourly (or 15 minutes) universal mixes with the use profiles of heating, lighting, cooling or ventilation) and integrating them to annual values will result in annual use specific mixes.

b) Research assessment (project « ELCAB : **E**lectricity mixes in **L**ife **C**ycle **A**ssessments of **B**uildings: Methodology and application on residential and office buildings »,

Type of mixes	**Explanation / Intention**
General information : Goal of this project is to assess different approaches of modelling the electricity mix used in the phase of operation of buildings and to offer electricity mix LCI datasets for the different approaches and applications. The mixes are established on the basis of 15/60 minutes intervals, matched with generic electricity load profiles of residential and office buildings, and integrated to months, seasons and the year. Additionally, average mixes are applied. The differences in assessment when relying on data of different time granularity of electricity mix data (hourly, monthly, seasonal, annual), when following a consequential as compared to an attributional approach, and when applying present or future mixes will be identified. The table below describes all alternatives quantified and assessed. Results about the environmental performance of the different electricity mixes, final results including environmental assessments of the buildings according to SIA 2040 (see above) by mid 2020) Remark : All alternatives are applied on the country mix and selected ones additionally on the mix of the electricity supplier of the city of Zürich, ewz	
Today	
Annual average mixes	Three different mixes : descriptive, decision oriented and based on guarantees of origin Mixes include traded electricity according to economic/contractual information (commercial trade). The descriptive mixes are established using hourly and annual mix data and archetypical load profiles of residential and office buildings and of Switzerland.
Daily mixes	not addressed
Seasonal mixes	Summer and winter mixes descriptive only. Same as with annual average mixes
Future	

Type of mixes	Explanation / Intention
Annual average mixes 2035 and 2050	Descriptive mixes only. Mix based on scenario information provided in official documents, modelled in steps of five years
Option 1 : building integrated PV	Use profile adjusted according to production profile of PV plant, 2 different sizes of PV plant
Option 2 : building integrated PV plus battery	Use profile adjusted according to production profile of PV plant and battery usage ; adjustment of share of self consumption, 2 different sizes of battery.
Option 3 : building integrated PV plus electric car(s)	Use profile adjusted according to production profile of PV plant and electric car charging; adjustment of share of PV self consumption.
Allocation for exported PV	Exported PV electricity has the environmental profile of PV mounted/integrated in the building under assessment. If 100 % of PV electricity is exported, the environmental impacts of PV power plant manufacture attributed to the building is zero.

Criterion	**Swiss case (ELCAB):** Research assessment of different types of mixes depending on time horizon (present, future) LCA modelling approach and time granularity				
Generic or specific	provider specific	generic			
Geographic scope	continental	regional	national		
Electricity mix model					
Type of mix	(1) Production mix	(2) Supply mix			
Nature of trade flows	Physical flows	Flows based on contracts	Flows based on Guarantee of Origin (GO)		
Modelling choice for the supply mix	(1) Production + imports	(2) Production – exports + imports	(3) Production – Δ exports + Δ imports *NB: contemporaneous physical imports and exports are considered transit trade and thus balanced. Only net import and net export volumes (determined on an hourly or 15 min basis) are taken into account*	(4) According to national electricity declaration *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*	(5) Production minus Exports (Production volume – domestic GO supply volume, per technology) plus Imports (foreign GO supply volume, per technology) *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*
Balance of import/export at each border with the studied country and each neighbouring country	Gross balance	Net balance	Not applicable		

Data types for the energy carrier flows	Direct use of empirical data from Transmission System Operator (TSO)	Data derived from/determined with a model (e.g., statistical models…)	Other data (e.g., use of national statistics different from TSO data, literature data)		
End uses dependence [1]) (heating, lighting, cooling, etc.)	universal mix	use specific mix			
Time dimension	historical mix	present mix	future mix		
LCA modelling approach	average mix	marginal mix			
Time granularity	annual average mix	seasonally differentiated mix	hourly differentiated mix		
Allocation of in site PV electricity production	Impacts of self-consumed part only	Gross impacts minus PV impacts of fed in electricity	Gross impacts minus grid mix impacts of fed in electricity		

[1]): The mix (universal or use specific) may be defined on the level of annual, seasonal, daily, hourly or 15 minutes' averages. Combining hourly (or 15 minutes) universal mixes with the use profiles of heating, lighting, cooling or ventilation) and integrating them to annual values will result in annual use specific mixes.

c) Research assessment (project « ECODYNBAT : Dynamic Life Cycle Assessment of Buildings »,

Choices	**Explanation / Intention**
General information	The EcoDynBat project assesses the environmental impacts of the electricity demand of Swiss buildings with a dynamic perspective. The project identifies the influence of increased temporal precision on the environmental impact calculations for the electricity demand of Swiss buildings. It will propose different time steps to be chosen by the user of the EcoDynBat method & tool for the calculations, which offers a balance between modelling efforts and the representativeness of results. The environmental impacts of electricity consumed at the building level is modelled by considering: - the variability of the Swiss production mix (sources varying) - the variability of the Swiss imports in quantity and source; the imports mixes of the European neighboring countries and others are varying (cf. § 1.7.5, Switzerland, EcoDynBat approach for the explanation of the matrix-based calculations and the different levels of interest for the neighboring countries + also below in Geographical scope) From the building side, the following sources of variability are considered: - Electricity consumption profile - Presence and production profile of a decentralized electricity production system (photovoltaic in particular)
Generic mix	Generic mix (on an hourly basis) at the national level,

Choices	Explanation / Intention
Geographical scope	National but considers hourly interactions with the neighboring countries. Imports are varying in quantity but also in source (i.e. the neighboring countries mixes are varying over the time) Considered countries (cf. § 1.7.5, Switzerland, EcoDynBat approach for the justification of the choice of these six countries): - Switzerland, Austria, Italy, Germany, France, Czech Republic (variation over the time of their production mixes + imports) - Other countries are considered with constant environmental impacts for their production means and only the imports amounts are varying over the time
Type of mix	Consumer mix (production mix + imports + grid losses)
Imports / Exports modelling choice	Gross physical flows, Economic contracts not considered
Allocation method for the imports/exports	Based on the idea that national generation of electricity is combined with imported electricity mixes to offer the electricity to customers. The resulting electricity mix is consumed in the investigated supply area AND exported to neighboring countries on the other. This means that the electricity mix model is equivalent for both consumption and export mixes.
Use pattern dependence	Universal hourly mix, no distinctions per usage
Time dimension	Present mix (from January 2017 until December 2018) Use of most recent data and regular updates from TSOs and other data sources useful for feeding the EcoDynBat tool.
Modelling approach	Average mix, attributional
Time granularity	From hourly to annually (daily, monthly, seasonally)
Allocation for exported PV	Only the self-consumed part of the PV is allocated to the building, the rest is deemed to be part of the national mix. The share of PV electricity sent to the grid is calculated according to the building demand profile and the PV system production profile. The impact of PV electricity is function of its technology and its production (varying from one site to another).

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Criterion	**Swiss case (EcoDynBat):** Research assessment & computational tool of different types of mixes (modelling options) and time granularity			
Generic or specific	provider specific	generic		

Geographic scope	Continental[1]	regional	National[1]		
Electricity mix model					
Type of mix	(1) Production mix	(2) Supply mix			
Nature of trade flows	Physical flows	Flows based on contracts	Flows based on Guarantee of Origin (GO)		
Modelling choice for the supply mix	(1) Production + imports	(2) Production – exports + imports	(3) Production – Δ exports + Δ imports *NB: contemporaneous physical imports and exports are considered transit trade and thus balanced. Only net import and net export volumes (determined on an hourly or 15 min basis) are taken into account*	(4) According to national electricity declaration *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*	(5) Production minus Exports (Production volume – domestic GO supply volume, per technology) plus Imports (foreign GO supply volume, per technology) *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*
Balance of import/export at each border with the studied country and each neighbouring country	Gross balance	Net balance	Not applicable		
Data types for the energy carrier flows	Direct use of empirical data from Transmission System Operator (TSO)	Data derived from/determined with a model (e.g., statistical models…)	Other data (e.g., use of national statistics different from TSO data, literature data)		
End uses dependence [2]) (heating, lighting, cooling, etc.)	universal mix	use specific mix			
Time dimension	historical mix	present mix	future mix		
LCA modelling approach	average mix	marginal mix			
Time granularity	annual average mix	seasonally differentiated mix	hourly differentiated mix		
Allocation of in site PV electricity production	Impacts of self consumed part only	Gross impacts minus PV impacts of fed in electricity	Gross impacts minus grid mix impacts of fed in electricity		

[1]): The EcoDynBat computational tool is able to calculate national hourly electricity mix for Switzerland as well as for other European countries incl e.g., Germany, Spain, Portugal, Benelux,

Denmark etc. In that context, it has a continental perspective in the way that it is able to handle hourly import/export between Switzerland and the surrounding European countries (neighbouring ones and some others). ^{2}): The mix (universal or use specific) may be defined on the level of annual, seasonal, daily, hourly or 15 minutes' averages. Combining hourly (or 15 minutes) universal mixes with the use profiles of heating, lighting, cooling or ventilation) and integrating them to annual values will result in annual use specific mixes.

C.3 Example for Hungary

a) Mainstream assessment

Choice	Explanation / Intention
Generic mix	A generic mix is applied from a generic database (ecoinvent).
National mix	National mix is applied, with imports and exports according to data availability in generic databases.
Supply mix	National mix is applied, with imports and exports according to data availability in generic databases.
Generic mix	No differentiation between different use types (such as heating, cooling, ventilation, hot water etc.) ; electricity consumption of all uses are modelled with the same mix.
Present or future mix ?	The average present (recent past) electricity mix is applied.
Average or marginal mix ?	Average electricity mix.
Annual mix	An annual mix is applied.
Allocation for exported PV	100% of avoided impacts, assuming a potential replacement of the Hungarian electricity mix.

b) Research assessment, linking life cycle assessment and the European Electricity Market Model (EEMM) of the Regional Centre for Energy Policy Research (REKK), and the Green-X model, developed by the Energy Economics Group of the Vienna University of Technology.

Choice	Explanation / Intention
General information	The assessment of the environmental impact of the Hungarian electricity mix was carried out in a research project. The objective was to link life cycle assessment with an economic electricity market model to study the temporal variation in the environmental impact of the current and future electriticy mix. EEMM is a partial equilibrium microeconomic (supply-demand) model. It assumes a fully liberalised electricity market and perfect competition in all modelled countries. In every country, the model calculates the merit-order curve, assuming all production units offer their electricity on a marginal-cost basis. Supply includes imports as well, taking into account capacity constraints. EEMM includes 3400 power plant units in a total of 41 markets, including the EU, Western Balkans and other EU neighbouring countries. Each country is a single node in the model, with 104 interconnectors between them.
Generic mix	Generic mix for Hungary
National mix	National mix but interactions with neighbouring countries are considered. Imports are modelled as the production mix of the neighbouring countries (excluding their imports). The model assumes that the composition of the electricity that is exported is the same as the electricity supplied to the grid.
Supply mix	Production mix + imports
Universal or Use-specific mix	Universal mix, but the possibility of developing use-specific mix will be studied
Present or Future mix ?	Present mix and future mix. Future mix is based on three policy scenarios, based on the economic electricity market model.
Average or marginal mix ?	Average mix
Annual and hourly mix	Besides the annual mix, also a mix with an hourly resolution is modelled for the present and for the future scenarios.

Choice	Explanation / Intention
Allocation for exported PV	100% of avoided impacts assuming a potential replacement of the Hungarian electricity mix.

References:

Kiss, Benedek ; Szalay, Zsuzsa ; Kácsor, Enikő: Environmental impacts of future electricity production in Hungary with reflect on building operational energy use. In: Robby, Caspeele; Luc, Taerwe; Dan, M. Frangopol - Life Cycle Analysis and Assessment in Civil Engineering: Towards an Integrated Vision LONDON : CRC Press, (2019) pp. 847-853. , 7 p.

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HUNGARY

Criterion	HUNGARY Mainstream assessment				
Generic or specific	provider specific	generic			
Geographic scope	continental	regional	national		
Electricity mix model					
Type of mix	(1) Production mix	(2) Supply mix			
Nature of trade flows	Physical flows	Flows based on contracts	Flows based on Guarantee of Origin (GO)		
Modelling choice for the supply mix	(1) Production + imports	(2) Production – exports + imports	(3) Production – ∆ exports + ∆ imports *NB: contemporaneous physical imports and exports are considered transit trade and thus balanced. Only net import and net export volumes (determined on an hourly or 15 min basis) are taken into account*	(4) According to national electricity declaration *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*	(5) Production minus Exports (Production volume – domestic GO supply volume, per technology) plus Imports (foreign GO supply volume, per technology) *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*
Balance of import/export at each border with the studied country and each neighbouring country	Gross balance	Net balance	Not applicable		

Data types for the energy carrier flows	Direct use of empirical data from Transmission System Operator (TSO)	Data derived from/determined with a model (e.g., statistical models…)	Other data (e.g., use of national statistics different from TSO data, literature data)		
End uses dependence 1) (heating, lighting, cooling, etc.)	universal mix	use specific mix			
Time dimension	historical mix	present mix	future mix		
LCA modelling approach	average mix	marginal mix			
Time granularity	annual average mix	seasonally differentiated mix	hourly differentiated mix		
Allocation of in site PV electricity production	Impacts of self consumed part only	Gross impacts minus PV impacts of fed in electricity	Gross impacts minus grid mix impacts of fed in electricity		

1): The mix (universal or use specific) may be defined on the level of annual, seasonal, daily, hourly or 15 minutes' averages. Combining hourly (or 15 minutes) universal mixes with the use profiles of heating, lighting, cooling or ventilation) and integrating them to annual values will result in annual use specific mixes.

HUNGARY					
Criterion	**HUNGARY, REKK EEMM + LCA** Research assessment				
Generic or specific	provider specific	generic			
Geographic scope	continental	regional	national		
Electricity mix model					
Type of mix	(1) Production mix	(2) Supply mix			
Nature of trade flows	Physical flows	Flows based on contracts	Flows based on Guarantee of Origin (GO)		
Modelling choice for the supply mix	(1) Production + imports	(2) Production – exports + imports	(3) Production – Δ exports + Δ imports *NB: contemporaneous physical imports and exports are considered transit trade and thus balanced. Only net import and net export volumes (determined on an*	(4) According to national electricity declaration *NB: This model only works for countries such as EU and EFTA countries where*	(5) Production minus Exports (Production volume – domestic GO supply volume, per technology) plus Imports (foreign GO supply volume, per technology) *NB: This model only works for countries such as EU and EFTA countries where*

			hourly or 15 min basis) are taken into account	*electricity disclosure is mandatory*	*electricity disclosure is mandatory*
Balance of import/export at each border with the studied country and each neighbouring country	Gross balance	Net balance	Not applicable		
Data types for the energy carrier flows	Direct use of empirical data from Transmission System Operator (TSO)	Data derived from/determined with a model (e.g., statistical models…)	Other data (e.g., use of national statistics different from TSO data, literature data)		
End uses dependence [1]) (heating, lighting, cooling, etc.)	universal mix	use specific mix			
Time dimension	historical mix	present mix	future mix		
LCA modelling approach	average mix	marginal mix			
Time granularity	annual average mix	seasonally differentiated mix	hourly differentiated mix		
Allocation of in site PV electricity production	Impacts of self consumed part only	Gross impacts minus PV impacts of fed in electricity	Gross impacts minus grid mix impacts of fed in electricity		

[1]): The mix (universal or use specific) may be defined on the level of annual, seasonal, daily, hourly or 15 minutes' averages. Combining hourly (or 15 minutes) universal mixes with the use profiles of heating, lighting, cooling or ventilation) and integrating them to annual values will result in annual use specific mixes.

C.4 Example for Sweden

a) Modelling of the electricity mix following the EU Joint Research Center method (Erlandsson, 2019; Moro & Lonza, 2018), used e.g. in the NollCO$_2$ certification scheme

Choice	**Explanation / Intention**
Generic mix	The method is meant to provide a value appropriate to assess all buildings in Sweden, regardless of the energy provider. However, producer-specific emission factors may also be used in the NollCO$_2$ certification, if they have been calculated in a preexisting EPD or if they have received the "Bra Miljöval" certification.

Choice	Explanation / Intention
National mix	The Swedish Energy Agency now recommends using a national mix, primarily for the sake of harmonization and consistency with practices in other European countries.
Supply mix, considering Swedish production plus imports minus exports and transmission losses.	This method calculates the life cycle based emission factor for electricity consumed in a country. One objective is to consider electricity trading between European countries, hence the inclusion of both imports and exports. The original JRC method ignored upstream emissions for renewable energy, but the value calculated for the NollCO$_2$ certification includes the embodied impact of renewable power plants.
Universal mix	The aim is to obtain an average factor for attributional LCAs that can be used regardless of the context or system studied.
Data on physical flows from transmission system operators.	The method is based on data from the ENTSO-E transparency platform, IEA and Eurostat.
Present / future mix	The original work from the EU Joint Research Center only provides an emission factor for the year 2013. The NollCO$_2$ certification scheme updates this value every two years, and also includes a future scenario. Following long term strategies from Sweden and the EU, electricity is assumed to be carbon neutral in 2050. Emission factors between 2020 and 2050 are estimated through linear interpolation. Another report by Erlandsson (2019) also develops a method to assess future greenhouse gas emissions from the building sector, based on forecasts from the Swedish Energy Agency.
Average mix	This emission factor is meant to be used for accounting and certification purposes. However, it should be noted that “negative emissions” from on-site electricity exported to the grid are estimated using a marginal approach.
Annual average mix	Temporal variation is not accounted for, for the sake of simplicity. Previous works suggest that there is little difference between using yearly averages and hourly values when considering an average mix for attributional LCAs (Erlandsson et al., 2018).
Allocation for exported electricity	In NollCO$_2$, electricity exported to the grid results in negative greenhouse gas emissions by offsetting electricity produced in coal power plants (i.e. it receives a “negative emission factor” corresponding to the emission factor of coal power). This only applies to electricity that would be produced in excess of the building’s needs. In other words, on-site electricity is first assumed to reduce the building’s electricity demand, and the production that exceeds the building’s demand is assumed to displace coal power.

SWEDEN					
Criterion	JRC Method as used in NollCO$_2$				
Generic or specific	Provider specific	Generic			
Geographic scope	Continental	Regional	National		

Electricity mix model					
Type of mix	Production mix	Supply mix			
Nature of trade flows	Physical flows	Flows based on contracts	Flows based on Guarantee of Origin (GO)		
Modelling choice for the supply mix	(1) Production + imports	(2) Production – exports + imports	(3) Production – ∆ exports + ∆ imports *NB: contemporaneous physical imports and exports are considered transit trade and thus balanced. Only net import and net export volumes (determined on an hourly or 15 min basis) are taken into account*	(4) According to national electricity declaration *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*	(5) Production minus Exports (Production volume – domestic GO supply volume, per technology) plus Imports (foreign GO supply volume, per technology) *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*
Balance of import/export at each border with the studied country and each neighbouring country	Gross balance	Net balance	Not applicable		
Data types for the energy carrier flows	Direct use of empirical data from Transmission System Operator (TSO)	Data derived from/determined with a model (e.g., statistical models…)	Other data (e.g., use of national statistics different from TSO data, literature data)		
End uses dependence 1) (heating, lighting, cooling, etc.)	universal mix	use specific mix			
Time dimension	historical mix	present mix	future mix		
LCA modelling approach	average mix	marginal mix *(only for electricity exported to the grid)*			
Time granularity	annual average mix	seasonally differentiated mix	hourly differentiated mix		
Allocation of in site PV electricity production	Impacts of self consumed part only	Gross impacts minus PV impacts of fed in electricity	Gross impacts minus grid mix impacts of fed in electricity		

b) Tidstegen tool for consequential assessments of energy-related measures (Gode et al, 2015)[26]

Choice	**Explanation / Intention**
Generic mix	The method assesses the consequences of a change in demand on the Nordic electricity grid, regardless of the producer.
Regional mix	The assessment is based on a Nordic electricity mix, due to the fact that Nordic countries share a common market (Nordpool).
Supply mix, considering Nordic production, imports and exports.	The Tidstegen method calculates the consequences of a change of electricity demand, depending on the season and time of day when it happens. Possible consequences are changes in how plants are operated, changes in investments in various production technologies, and changes in imports and exports.
Universal mix	The aim is to obtain an emission factor for consequential LCAs that can be used to assess any energy-related measure at the building level.
Data derived from a model.	A linear programming cost optimization model is used to determine the consequences of a change in demand on the operation of power plants and investments in new power plants, depending on when this change in demand happens.
Future mix	The Tidstegen tool focuses on consequences up to the year 2040. The method is based on three future scenarios, that differ primarily in terms of carbon costs.
Marginal mix (short- and long-term margin)	This method is meant to assess the consequences of a change in electricity demand on the operation of power plants, imports, exports and long-term investments in production technologies.
Seasonal mix	A separate marginal mix is calculated for each year until 2040. For each year, a separate mix is calculated for summer, spring/autumn, and winter. For each season, a separate mix is calculated for daytime and nighttime.
Allocation for exported electricity	On-site electricity exported to the grid is treated as a reduction in electricity demand on the grid.

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SWEDEN			
Criterion	**Tidstegen method**		
Generic or specific	Provider specific	Generic	

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[26] https://www.ivl.se/sidor/vara-omraden/miljodata/verktyget-tidstegen-for-klimatbedomning-av-energiatgarder.html

Geographic scope	Continental	Regional	National		
Electricity mix model					
Type of mix	Production mix	Supply mix			
Nature of trade flows	Physical flows	Flows based on contracts	Flows based on Guarantee of Origin (GO)		
Modelling choice for the supply mix	(1) Production + imports	(2) Production – exports + imports	(3) Production – Δ exports + Δ imports *NB: contemporaneous physical imports and exports are considered transit trade and thus balanced. Only net import and net export volumes (determined on an hourly or 15 min basis) are taken into account*	(4) According to national electricity declaration *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*	(5) Production minus Exports (Production volume – domestic GO supply volume, per technology) plus Imports (foreign GO supply volume, per technology) *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*
Balance of import/export at each border with the studied country and each neighbouring country	Gross balance	Net balance	Not applicable		
Data types for the energy carrier flows	Direct use of empirical data from Transmission System Operator (TSO)	Data derived from/determined with a model (e.g., statistical models…)	Other data (e.g., use of national statistics different from TSO data, literature data)		
End uses dependence 1) (heating, lighting, cooling, etc.)	universal mix	use specific mix			
Time dimension	historical mix	present mix	future mix		
LCA modelling approach	average mix	marginal mix			
Time granularity	annual average mix	seasonally differentiated mix	hourly differentiated mix		
Allocation of in site PV electricity production	Impacts of self consumed part only	Gross impacts minus PV impacts of fed in electricity	Gross impacts minus grid mix impacts of fed in electricity		

C.5 Example for Denmark

	Criterion	**Insert your country:………………………** Type of approach (e.g., commonly used approach (labelling systems), research assessment/study)				
1	**Generic or specific**	provider specific	generic			
2	**Geographic scope**	continental	regional	national		
3	**Electricity mix model** **Type of mix**	(1) Production mix	(2) Supply mix			
4	**Nature of trade flows**	Physical flows	Flows based on contracts	Flows based on Guarantee of Origin (GO) purchase together with physical production	Flows based on Guarantee of Origin (GO)	
5	**Modelling choice for the supply mix**	(1) Production + imports	(2) Production – exports + imports	(3) Production – Δ exports + Δ imports *NB: contemporaneous physical imports and exports are considered transit trade and thus balanced. Only net import and net export volumes (determined on an hourly or 15 min basis) are taken into account*	(4) According to national electricity declaration *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*	(5) Production minus Exports (Production volume – domestic GO supply volume, per technology) plus Imports (foreign GO supply volume, per technology) *NB: This model only works for countries such as EU and EFTA countries where electricity disclosure is mandatory*
6	**Balance of import/export at each border with the studied country and each neighbouring country**	Gross balance	Net balance	Not applicable		
7	**Data types for the energy carrier flows**	Direct use of empirical data from Transmission System Operator (TSO)	Data derived from/determined with a model (e.g., statistical models…)	Other data (e.g., use of national statistics different from TSO data, literature data)		
8	**End uses dependence 1)** (heating, lighting, cooling, etc.)	universal mix	use specific mix			

9	**Time dimension**	historical mix	present mix	future mix		
10	**LCA modelling approach**	average mix	marginal mix			
11	**Time granularity**	annual average mix	seasonally differentiated mix	hourly differentiated mix		
12	**Allocation of in site PV electricity production**	Impacts of self consumed part only	Gross impacts minus PV impacts of fed in electricity	Gross impacts minus grid mix impacts of fed in electricity		

[1]): The mix (universal or use specific) may be defined on the level of annual, seasonal, daily, hourly or 15 minutes' averages. Combining hourly (or 15 minutes) universal mixes with the use profiles of heating, lighting, cooling or ventilation) and integrating them to annual values will result in annual use specific mixes.

Annex D: Electricity mix considered in the case of PV production on the building

Local PV production can be self-consumed or exported. The self-consumed part may reduce the use of grid electricity. How should in situ produced electricity which is exported (fed into the grid) be modelled in the LCA of a building? Which production mix should be considered if following an avoided burden approach? This annex presents the situation and modeling choices in the different countries.

D.1 France

The electricity consumption has been approximately constant these last 12 years. Small variations are mainly related to winter temperature variations because of the use of electric heating. If the grid mix still includes a share of fossil or nuclear, it would not be logical to reduce the wind or hydro-electricity production when a PV roof reduces the consumption in a building.

During these 12 years, the electricity mix has varied: the share of nuclear production decreased from 78% to 72% and coal power plants from 5% to 1% whereas the share of renewables (wind, PV and biomass) increased from 1% to 9%, hydroelectricity varying a little according to rainfalls. The new renewable production is therefore replacing nuclear and coal production. The French energy transition policy planned to reduce the share of nuclear production to 50% in 2025, but this has recently been delayed until 2035. If only 6% has been replaced in 12 years, it would need 56 years to reach a 50% share considering the present speed of the transition. The last coal power plants are used for the winter peak demand. Local PV production is higher during the other seasons. It is therefore probable that a PV system with a life span of 30 years will replace a nuclear production. An electricity mix model allows to evaluate this in a more precise way.

Accounting for the benefit of exporting electricity allows a correct evaluation of the environmental pay back time of renewable energy systems. For instance the actual energy pay back time of a PV module is a few years (depending on the climate).

Using the avoided impacts approach, the environmental balance does not depend on the self-consumption ratio. In an example case study, this ratio is around 50% at the scale of a building but at the scale of the neighbourhood, because some other buildings consume the produced electricity, the self-consumption ratio is 100%. The avoided impacts approach leads to equal energy pay back times, which is physical. The avoided impacts method provide consistent results which are scalable: the environmental pay back time is the same at the scale of the product, the building, the neighbourhood and the city.

D.2 Switzerland

Switzerland decided to step out of nuclear power. It is not allowed to commission new nuclear power plants and the existing ones may operate as long as they fulfill the safety requirements. Currently 4 nuclear power plants (located at three sites) are still running. The fifth one stopped production at the end of 2019. The energy directive includes goals for the electricity production with new renewable energies (11’400 GWh per year in 2035 compared to 3’670 GWh in 2018) and with hydroelectric power plants (37’400 GWh per year in 2035 compared to the average expected annual production of 35’210 GWh).

The technical bulletin SIA 2040 specifies how to model electricity produced in situ and exported to the electricity grid. Firstly, the environmental impacts of in situ electricity production (e.g. photovoltaic system, combined heat and power plant) are quantified and attributed to the total amount of kWh produced, i.e. the electricity exported and the electricity self-consumed. The environmental impacts of the self-consumed electricity are attributed to the building, whereas the environmental impacts of the exported electricity are attributed to the organisation (e.g. electric utility, private households) purchasing it. It is not allowed to attribute any kind of negative environmental burdens to the building’s LCA due to exported electricity.

D.3 Sweden

Electricity production in Sweden is based primarily on hydropower and nuclear power (about 40% of the production mix each), followed by windpower and combined heat and power plants (about 10% of the production mix each). Sweden is a net exporter of electricity.

There is currently no standardized method to account for the benefits of on-site PV electricity exported to the grid. Different assessments might use different methods. This situation is likely to evolve in the coming years, as there are ongoing efforts towards more harmonization.

Both the current version of the NollCO$_2$ certification method (Sweden Green Building Council, 2020), and the Tidstegen method (Gode et al., 2015), assume that the short term marginal consequences of exporting on-site electricity to the grid are a reduction of electricity production in coal power plants. Therefore, in both cases, a negative emission factor would be used, equal to the emission factor of electricity produced in coal power plants.

The two methods differ regarding the way they assess exported on-site electricity in the long term. NollCO$_2$ considers that electricity production in Europe will be climate neutral by 2050, following the objectives of Sweden and the EU. The emission factor of electricity (both for electricity used in the building, and for on-site electricity exported to the grid) is assumed to decrease linearly between 2020 and 2050. Tidstegen considers three different scenarios after 2020. In the long term, it is assumed that the marginal emission factor for electricity will depend on the time: the marginal mix is not assumed to be coal in the long term, but varies depending on the season and whether it is day or night. In Tidstegen, any energy-related measure at the building level would have to be assessed in each of these three long term scenarios. The model requires inputing hourly data for electricity demand, but the calculations only consider the total daytime (respectively nighttime) electricity demand for each season and each year.

NollCO$_2$ specifies that this marginal assessment only concerns on-site electricity produced in excess of the building's needs. On-site electricity would first be used to meet the building's electricity demand. Additionally, the embodied greenhouse gas emissions of the PV installation itself are taken into account in the emission factor of PV electricity. In other words, they are included in module B6 using values in gCO$_2$/kWh, rather than being included in module A.

D.4 Norway

There is no official electyricity mix to be considered for electricety mix regarding electricety produced by PV when exported to the grid.

However, the the Research Centre on Zero-Emission Buildings (ZEB), in the LCA for the validation of the "Zero-emission" uses a CO$_2$-factor of 132 g CO2eq/kWh, which is a modelled average CO$_2$-factor from Europe production between 2010 and 2050 (Graabak et al 2014). This value corresponds well with the Norwegian Standard on LCA of buildings (NS3720:2018) Scenario 2 (EU28+NO) for future electricity mix from 2015 to 2075 of 136 g CO$_{2eq}$/kWh.

The rationale behind the use of european future electricity mix is that the Norwagian grid is supposed to be fully integrated (withouth botlenecks) with the european grid, motivated by the tenmporal benefits of hydropower versus thermal powerproduction in buffering new-renewable electricity production in the grid.

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