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Development of an Energy Benchmarking Model for Municipalities to Estimate the Potential for Establishing a Renewable Energy Community

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Vienna, 13.02.2022

Affidavit

I, **MAG. (FH) THOMAS MOTSCH**, hereby declare

1. that I am the sole author of the present Master's Thesis, "DEVELOPMENT OF AN ENERGY BENCHMARKING MODEL FOR MUNICIPALITIES TO ESTIMATE THE POTENTIAL FOR ESTABLISHING A RENEWABLE ENERGY COMMUNITY", 83 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 13.02.2022

Signature

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Finally, I would like to express my deepest gratitude to my family. Johannes, Philipp and Katharina for their love and happiness. And especially my wife Maria for her unconditional love and support not only during the last two years of study.

Learning and innovation go hand in hand.
The arrogance of success is to think that what you did yesterday
will be sufficient for tomorrow.

(William Pollard)

Abstract

In order to meet the renewable energy targets for Europe, decentralized renewable electricity generation will play a crucial role. For Austria, an important path towards increasing electricity from renewable sources and towards decentralization has been cleared in the Erneuerbaren-Ausbau-Gesetz (Renewable Energy Expansion Act) by introducing Energy Communities. In this work a detailed overview of energy communities is being provided. Based on the legal framework, energy communities are analysed from different perspectives.

Building on this theoretical foundation, a model is introduced that supports local authorities in Lower Austria in estimating a municipality's potential for establishing a renewable energy community using PV modules on the roof of typical community buildings.

In a first step, the generation potential of the different buildings can be estimated. Here, parameters like roof type, building orientation, roof area, tilt angle of the roof are incorporated. In a second step, the own electricity consumption of the buildings is estimated based on the floor size and the type of the buildings. The surplus of PV generation and own demand can be used as basis for establishing a renewable energy community. In addition to the surplus calculation, the consumption of the surplus by different consumer groups and their respective consumption patterns are investigated. Annual data are not meaningful in this context as PV generation and electricity demand show different seasonal patterns. Therefore, monthly data are analysed during the different steps of the model.

The model is set up for an easy usability by local authorities. The model calculation is implemented using a common spreadsheet software. With the help of this work and the developed model, local authorities should be able to play an active role in increasing the renewable electricity share and support the decentralization of the energy system.

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1 Introduction

1.1 Motivation

The world is facing a climate crisis. The observed global temperature is rising. Reaching the target of 1,5 degree Celsius of manmade global temperature increase is crucial to restrict the impacts of climate change (IPCC, 2018).

The European union is leading the global climate efforts. Europe is striving to be the first climate-neutral continent by 2050. As a first step, the European Commission introduced its plan to reduce European emissions by 55% by 2030 (European Commission, 2021).

To reach the European emission reduction targets, immediate action must be taken. One key success factor to reach this goal will be the increase of decentralized renewable energy generation (Weckesser et al., 2021).

For Austria, the goals of reaching climate neutrality are even more ambitious. Austria is set to be climate neutral by 2040. As an intermediate target total electricity consumption shall be 100% from renewable sources by 2030 – on balance. As illustrated below, the share of fossile electricity generation in 2020 amounts to around 18%.

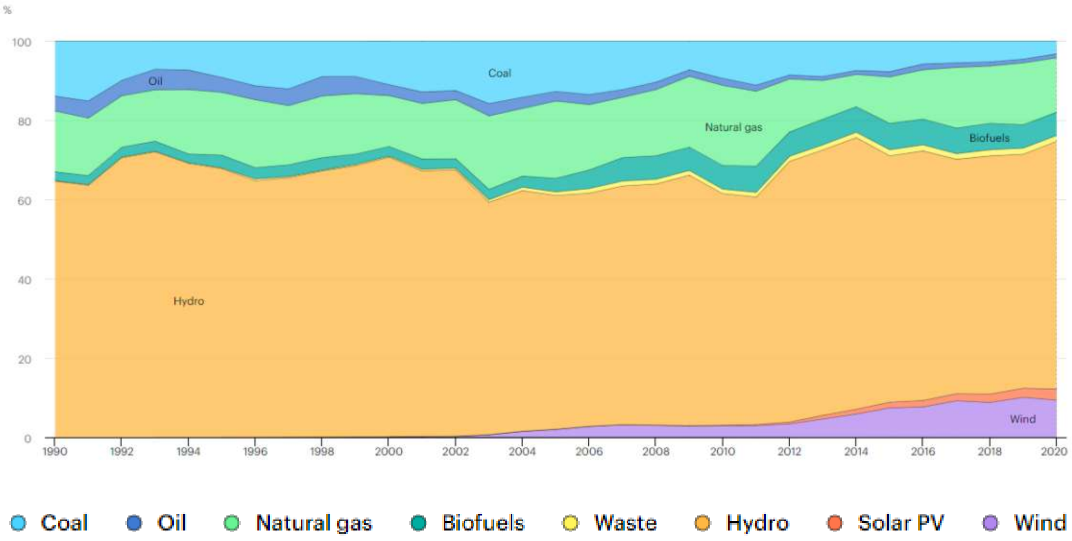


Fig 1: Austrian electricity generation by source 1990-2020 (IEA, 2021)

For Austria, an important path towards increasing electricity from renewable sources and towards decentralization has been cleared in the Erneuerbaren-Ausbau-Gesetz (Renewable Energy Expansion Act) (EAG) by introducing Energy Communities. Those Energy Communities pave the ground for various market participants to generate renewable energy as part of such an Energy Community and make it available to other members of the same Energy Community. Among others, also municipalities and its citizens can be part of energy communities.

This concept can be suitable not only for large municipalites but could also be applied to small villages as almost every village owns some typical municipal buildings, i.e. townhall, kindergarten, construction yard, etc..

However, local authorities often do not have detailed knowledge about renewable energy legislation and technologies. Therefore, an easily understandable and applicable model is needed to help those authorities estimating the community's potential for generating electricity from renewable sources and to provide part of this electricity to its citizens.

As Lower Austria represents the largest state within Austria, this state is selected as a basis for developing this model.

For the state of Lower Austria, a Climate and Energy Roadmap 2020 to 2030 (NÖ Klima- und Energiefahrplan 2020 bis 2030) was published in 2019 already. This roadmap also provides a future picture of energy consumption and its sources up to 2050. Renewable Energies should increase considerably while fossile energy carriers should vanish until 2050. Renewable Energy Communities (RECs) are not mentioned explicitly in this roadmap, however a clear target on citizens' participation is given. Until 2040 every citizen of Lower Austria should be engaged in renewable energy production – either directly or indirectly.

Another issue that roadmap is referring to is the role of the municipalities as positive role models for the citizens. In addition, municipalities that are role models related to energy bookkeepings (Energiebuchhaltungs-Vorbildgemeinden) are pointed out as best practice examples.

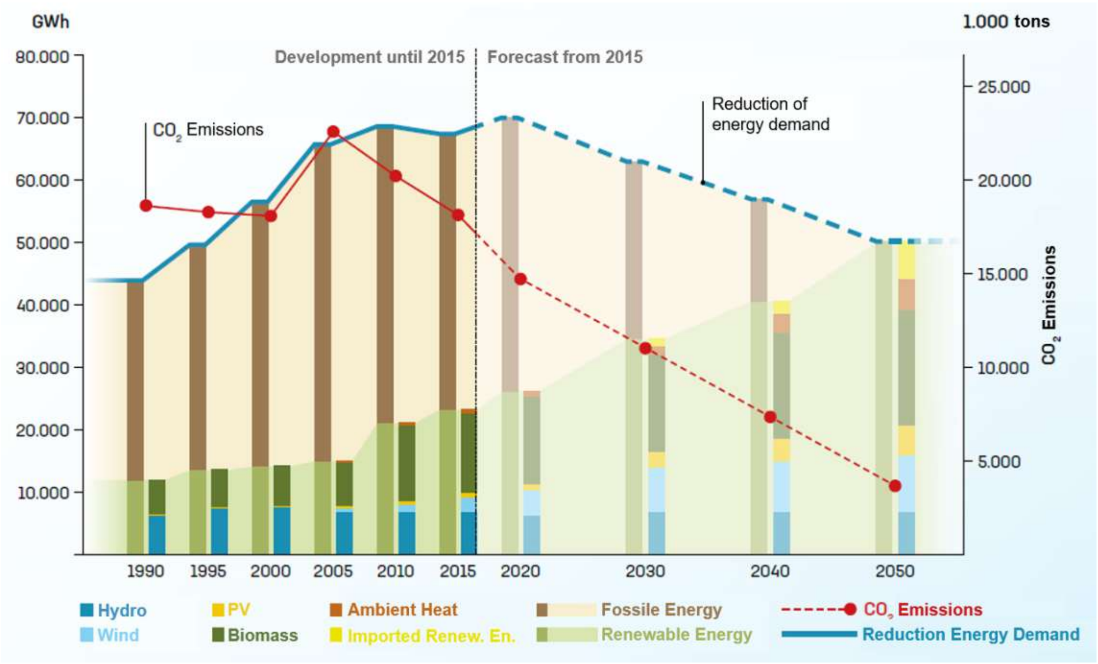


Fig 2: Future picture of energy consumption and sources up to 2050 (NÖ Klima- und Energiefahrplan 2020 bis 2030)

In 2021, based on this roadmap a detailed action plan was released for the period of 2021 to 2025. The action plan is structured in seven programs with one focusing on energy and supply. Among the actions suggested in this program, the state of Lower Austria commits itself to support citizen participation projects and Energy Communities. Three major steps are outlined for successful implementation of this commitment:

- Development of standardized contracts and models
- Consideration of starting an umbrella organization for ECs
- Campaigning for a legal framework at the federal level to support successful citizen participation projects.

Based on the positive framework conditions in Lower Austria, municipalities have the opportunity to involve its citizens in the energy transition by starting a REC. This work aims to contribute by developing a easily accessible tool for local authorities to assess their potential to start a REC.

1.2 Core objective of this work

The core objective of this work is the development of a technical model for municipalities to estimate their potential of establishing a Renewable Energy Community according to the EAG. The model is particularly applicable to municipalities in Lower Austria. This region was chosen, because it is the largest state within Austria and therefore has the highest number of municipalities among all nine Austrian states, as well as positive framework conditions for RECs and a good data availability.

The model will have three major parts:

1) The supply side: The model estimates the energy generation potential of typical communal buildings via rooftop photovoltaics (PV) according to its roof type and its orientation.
2) The demand side: The model uses benchmarking ratios derived from the energy bookkeeping of municipalities to estimate the energy self demand.
3) The usage of the electricity surplus: The model estimates how many households could be partly supplied by the generated electricity.

The target group of this work are local authorities like mayors, members of municipal councils or energy officers in larger municipalities.

This work is focusing on the technological aspect of estimating electricity supply and demand within a municipality. Commercial aspects are not included into the developed model and can be part of further analyses. Additionally, the incorporation of storage solutions or charging points for electric vehicles is not explored. The model could in the future be adapted to account for those electricity demand applications as well. At the moment, the model focuses on PV generation and calculating the self demand of the buildings as this is today’s reality for most municipalities.

1.3 Organization and approach of this work

The first chapter of this thesis is an introduction to the work and gives details about the motivation behind this work and the core objective and target group of this work.

In the second chapter, background information on energy communities is being provided. Here, firstly the regulatory framework on a European and Austrian level is discussed. Particularly the recent Austrian legislation of EAG is focused on. In a next step, energy communities are analyzed from different perspectives:

- Who are the actors of ECs?
- What are enabling and disabling factors for ECs?
- Which challenges ECs have to face?
- What kind of impact can ECs achieve?
- What role do ECs play in delivering energy justice?

For this chapter literature was reviewed and used as reference.

In the next chapter the model itself is explained in detail. Here a distinction is made between estimating the generation potential and estimating the own electricity consumption of different building categories. When estimating the generation potential, the following parameters are discussed in detail:

- roof type
- building orientation
- roof area
- tilt angle of roof
- performance ratio of the PV system

For the own electricity consumption, the average electricity demand per building category is discussed in detail.

In addition, this chapter gives details on the calculation of electricity surplus and the usage of this surplus electricity for different consumer groups.

Input variables in this chapter are based on literature research. The model developed and described in this thesis is a technological model. The electricity generation potential as well as the electricity demand are estimated based on technological potentials and empirical values respectively.

In the fourth chapter the results of this work will be presented.

The final chapter concludes the work and gives suggestions for further extensions of the developed model. Furthermore, new directions of research are suggested.

This work represents todays know-how and technological standard. The developed model is an estimation model and as such the results are estimates and can give an indication of realistic generation and demand levels. Before a decision is made, a detailed analysis should be done, also covering commercial aspects.

2 Background information on energy communities

2.1 Introduction to energy communities

In 2021 the European Commission proposed legislative changes in the so-called “Fit-for-55” package. Among other accentuations, EU’s renewable energy target in this proposal increases from 32% to 40% by 2030 (European Commission, 2021).

In order to increase the share of renewable energy, among other initiatives Decentralized Energy Resources (DERs) were emphasized. Within this transition of the energy system, the roles and the possibilities of citizens have evolved. Citizens now can act as producers and consumers (Kalkbrenner and Roosen, 2016) or prosumers (Butenko, 2016).

Renewable energy prosumers can be active participants on the energy markets. If acting together collectively, they can use different organisational forms and structures (Ruotsalainen et al., 2017, Gui and MacGill, 2018).

So far literature concerning collective prosumerism has focused on concepts like “community solar”, “community energy”, etc. (Bauwens and Devine-Wright, 2018; Capellan-Perez et al. 2018). It is expected that the diversity will increase due to the evolvement of new business models and new technological solutions.

Within the current EU legislation on renewable energies, the recast of the Renewable Energy Directive (Directive (EU) 2018/2001) also referred to as RED II, and the recast of the Electricity Directive (Directive (EU) 2019/944) also referred to as ED, are the most relevant pieces for this work.

In Article 2.16 of the RED II, Renewable Energy Commmunities (RECs) are defined as legal entities with open and voluntary participation, which are member-controlled and located in the proximity of the renewable energy projects that are owned and developed. Shareholders or members can be natural persons, small or medium enterprises or local authorities. In this article the primary purpose of a REC is defined as providing environmental, economic and social community benefits to its members rather than financial profits.

Article 22.2 stipulates that RECs are entitled to produce, consume, store and sell renewable energy, as well as share the produced renewable energy within the community and in addition access all suitable energy markets both directly of through aggregation in a non-discriminatory manner.

Article 22.2 stipulates that renewable energy communities shall be entitled to: (a) produce, consume, store and sell renewable energy, including through renewables power purchase agreements;

(b) share, within the renewable energy community, renewable energy that is produced by the production units owned by that renewable energy community, subject to the other requirements laid down in this Article and to maintaining the rights and obligations of the renewable energy community members as customers;

(c) access all suitable energy markets both directly or through aggregation in a non-discriminatory manner.

Article 22.4 (f) calls for the inclusiveness of RECs by emphasizing the accessibility to all consumers, including those in low-income or vulnerable households.

Despite this call for non-discrimenatory participation, no guidelines or measures are provided in the RED II to ensure this inclusiveness.

In Article 2.11 of the ED a “Citizen Energy Community” (CEC) is being defined. This definition is similar to RECs, but CECs may also be active in operating grid infrastructure, aggregation, energy efficiency services or “other” energy services. One major difference between RECs and CECs is the restriction of CECs on the electricity sector only, whereas RECs can also be active in other energy sectors. In contrast, CECs have no geographical restricition, while RECs can act only locally.

This work focuses on RECs as the local proximity is important for the municipalities and several advantages apply only to RECs.

The above-mentioned EU legislation has to be transposed to national laws. Campos et al. (2020) conclude that collective self-consumption laws are not enough to provide a robust legal framework for RECs. RECs require a specific legal framework. In addition, they see a need for countries to set clear and ambitious targets for decentralized renewable energy production until 2030 and

2050. In Austria this legal framework was passed in October 2021 as Erneuerbaren-Ausbau-Gesetz (EAG).

2.2 Introduction to Erneuerbaren-Ausbau-Gesetz (EAG)

In Austria, the Renewable Energy Expansion Act Package (Erneuerbaren-Ausbau-Gesetzes-Paket, EAG) aims to implement the RED II.

With the EAG package a new framework for subsidies is introduced in form of a market premium model (Marktprämienmodell) and through investment grants (Investitionszuschüsse). Furthermore, the establishment of a Renewable Energy Promotion Agency (EAG-Förderstelle), regulations for monitoring and transparency and a framework for energy communities are introduced. The EAG package also amends other legislative acts, which are the Gas Industry Act 2011 (Gaswirtschaftsgesetz 2011, GWG 2011) and the Electricity Industry and Organizations Act 2010 (Elektrizitätswirtschafts- und -organisationsgesetz 2010, ElWOG 2010).

2.2.1 Renewable Energy targets in the EAG

The EAG persues the goal of covering 100% of electricity consumption (on balance) in Austria by 2030 from renewable energy sources. To reach this goal the share of renewable energy sources for electricity production needs to be expanded by 27 TWh, which represents a 50% increase compared to the year 2018. The targeted increase broken down by renewable energy sources is illustrated below:

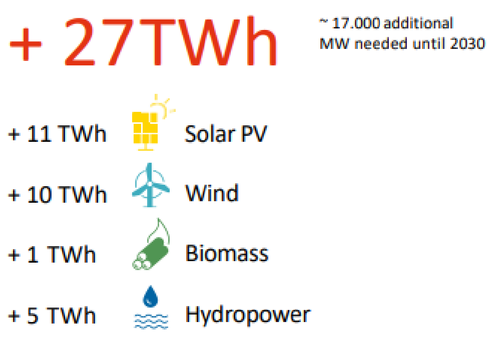


Fig 3: Breakdown of targeted renewable energy increase by source (EAG, 2021)

2.2.2 Subsidies and the Market Premium model

The financial support for renewable energies is one of the key aspects of the EAG package. The volume of financial support is targeted to be 1 billion Euros per year. The support measures can be either one-off investment grants or variable market premiums. The market premiums will be granted for 20 years.

Among the procedure of market premiums, a distinction is made between different technologies. For PV and biomass plants, the market premiums are awarded based on competitive tenders. For wind, hydropower and small biomass plants, the premiums will be awarded based on an application system. Beginning in 2024 only, the application system for wind power could be changed to a tendering system if such a system could lead to more efficient results.

Investment subsidies will be granted for construction and expansion of PV plants and storage, as well as for the construction of new wind power plants up to 1 MW.

The sources of the subsidies shall be levies in form of a flat-rate subsidy for renewable energy (*Erneuerbaren-Förderpauschale*) and a renewable subsidy contribution (*Erneuerbaren-Förderbeitrag*). All final consumers, which are connected to the public electricity grid will have to pay those two subsidies. Only low-income households will be exempted.

Related to the introduced market premium model, the EAG changed also the marketing for renewable energy producers. Within the previous fund scheme, renewable energy producers had a contract with the renewable energy processing agency (*OeMAG*) and received a remuneration in form of feed-in tariffs (FIT) for the electricity fed into the public grid. The FIT usually was above the market price and compensated for higher production costs.

The newly introduced market premium aims to offset the difference between the production costs for renewable electricity and the average market price for electricity. The market premium is granted only for electricity that is directly marketed and fed into the public grid.

2.2.3 Energy communities in the EAG

Energy communities according to the EAG are associations of one or more electricity producers and consumers for the purpose of generating, consuming, storing and selling renewable energy. In addition, energy communities can provide energy services for their members, e.g. charging services for electric vehicles, or can be active in the field of aggregation.

The EAG differentiates between renewable energy communities (*Erneuerbare-Energie-Gemeinschaften, EEGs*) with a regional scope and citizen energy communities (*Bürgerenergiegemeinschaften, BEGs*) with a supraregional scope. The major differences will be explained in the next chapter.

The primary focus of energy communities in the EAG is the participation of citizens, not entrepreneur participation. In the case of renewable energy communities, large companies and electricity and natural gas companies defined by GWG 2011 and ElWOG 2010 are in most cases excluded from being member of a renewable energy community.

2.2.4 Differences between RECs and CECs

RECs and CECs according to the Austrian EAG have some characteristics in common, but at the same time face differences in certain aspects. Kranebitter & Hecht (2021) provide an overview on those aspects.

Tab 1: Characteristics of RECs and CECs (Kranebitter & Hecht, 2021)

	Renewable Energy Commmunity	**Citizen Energy Community**
Main purpose	The main purpose is to provide environmental, social and economic benefits to the members and the areas in which it operates. A primary aspiration on financial gain is not allowed. The non-profit status must be either the result of the chosen legal	

	form of the community or be specified in the articles of association.	
Consumer Scope	Local & regional scope possible: Consumers and generation facilities are connected via low-voltage distribution network (local area) or via medium-voltage distribution network (regional area)	Supraregional scope: An extension across whole Austria is possible. Thus, the concession areas of various distribution system operators can be affected.
Legal form	At least two members are necessary to found a community. The legal form can be an association, cooperative, partnership or corporation, or similar associations with legal personality.	
Activities	Authorized activities are generation, consumption, storage and sale of renewable energy. Provision of aggregation and other energy services is also possible.	Authorized activities are generation, consumption, storage, and sale of electrical energy. Provision of aggregation and other energy services is also possible. Here no restriction to renewable sources exists.
Participation & Membership	Members and shareholders can natural persons, municipalities, legal entities of public authorities in relation to local services and other legal entities under public law or small and medium-sized enterprises. For private companies, taking part in the	Members and shareholders can be natural persons, legal entities, and local authorities. Decision-making power is restricted to members not engaging in commercial activities on a large scale and for which the energy industry is

	community must not be the main commercial or professional activity. Large companies and electricity and natural gas companies according to ElWOG and GWG are excluded.	not the primary area of business activity. Large and medium-sized companies are excluded from decision-making power.
Ownership of generation facilities	Owners can be either the communities themselves, their members, shareholders or third parties. The control of operation and disposal of the generation plants lies with the energy community. An exception applies in case of self-consumption of members who bring in a generation plant. Operation and maintenance can be delegated to a third party by the community. Thus, contracting and leasing models are possible.	
Surplus energy	An electricity trader can be contracted by the community to purchase the surplus energy not consumed. As an alternative, the surplus can also be allocated to the individual members according to their share.	
Power production	The quantity of electricity generated and consumed within an energy community remains outside of the balancing group system.	
Relationship between EC & network operator	A grid access contract must be concluded with the grid operator for each generation plant. In case of existing grid access contracts, the energy community can enter into the contractual relationship with the grid operator instead of the plant owner. Grid users have a legal claim against grid operators to be allowed to participate in energy communities. Energy Communities can also be owners and operators of a distribution network themselves.	

2.2.5 Advantages of energy communities in the EAG

Within this EAG package RECs play a crucial role. To support the establishment of those RECs, legislation provides specific benefits.

The total electricity costs for the consumer can be divided in three major categories: (1) electricity costs, (2) grid costs, and (3) legal fees comprising electricity fees and renewable energy supporting fees.

All three categories have variable parts that are dependent on the consumption in kWh and fixed parts which are independent of the actual consumption. For RECs the above-mentioned benefits affect the categories of grid costs and legal fees. The legislation of those benefits is spread over different legal acts.

The Elektrizitätswirtschafts- und –organisationsgesetz (ElWOG) adresses the grid costs of RECs.

§ 52 ElWOG stipulates a grid usage fee per metering point. However, in § 52 (2a) ElWOG is clarified that in case of RECs the grid usage fee for energy generated and consumed within a REC is calculated differently. Only for those voltage levels that are used within the REC a grid usage fee will be charged. In case of local range, only grid level 7 fees will be charged. In case of regional range, the fees for the grid levels 5, 6 and 7 will be charged. In both cases the grid levels 1 to 4 will not be part of the fee calculation for the amount of energy generated and consumed within the REC.

In practice charging not for the grid levels 1 to 4 leads to a discount in variable grid costs of -28% compared to the regular grid charges. This is true for the regional range (“Regionalbereich”).

In case of a local range (“Lokalbereich”), only grid level 7 is charged, and the level 1 to 6 are not part of the fee calculation. This results in a discount of -57%.

These discounts are rooted in § 5 (1a) Systemnutzungsentgelte-Verordnung (SNE-V 2018).

Elektrizitätsabgabegesetz (ELABG) and Erneuerbaren-Ausbau-Gesetz (EAG) adress the category of legal fees.

In § 2 Z4 ELABG a tax exemption is provided for electricity generated by photovoltaics within an energy community. The tax exemption is only applicable to the amount of electricity that is consumed within an energy community and not fed into the grid.

According to § 75 EAG, all end customers have to pay a contribution to supporting renewable energies (Erneuerbaren Förderbeitrag) linked to the grid usage fee. In § 75 (5) EAG an exemption for RECs is layed down. The amount of energy generated and consumed within a REC is not subject to this payable contribution to supporting renewable energies.

To give a practical example of the effects of the benefits for RECs a comparison is illustrated below. The basis of this example is an average 4-person household in Lower Austria with an electricity consumption of 4.000 kWh per annum. The variable electricity consumption price for consumption from the grid was assumed at 7,323 ct / kWh, which is in line with the prices of a local energy utility. The electricity price for consumption within the REC was assumed at 8,5 ct / kWh. This assumption was derived from already existing RECs in the region.

In the first table a regional REC was assumed, resulting in lower grid costs of -28%, whereas in the second table a local REC resulted in grid cost savings of -57%.

Tab 2: A practical example of savings with regional RECs (source: own calculations)

	without REC	with REC	Energy provider 70%	REC 30%	
Electricity consumption per annum	4.000	4.000	2.800	1.200	kWh
Variable consumption price (per kWh)	7,323		7,323	8,500	ct / kWh
Electricity costs (variable fee)	292,92	307,04	205,04	102,00	EUR
Electricity costs (fixed fee)	26,40	26,40	26,40		EUR
Electricity costs	**319,32**	**333,44**	**231,44**	**102,00**	**EUR**
Grid cost variable price (per kWh)	4,450		4,450	3,204	ct / kWh
Grid losses variable price (per kWh)	0,203		0,203	0,146	ct / kWh
Grid costs on consumption (variable fee)	178,00	163,05	124,60	38,45	EUR
Grid losses on consumption (variable fee)	8,12	7,44	5,68	1,75	EUR
Grid costs (fixed fee)	36,00	36,00	36,00		EUR
Metering costs (fixed fee)	26,16	26,16	26,16		EUR
Grid costs	**248,28**	**232,65**	**192,44**	**40,20**	**EUR**
Electricity tax (per kWh)	1,500		1,500		ct / kWh
Biomass subsidy (per kWh)	0,195		0,195		ct / kWh
Renewable Energy subsidy (per kWh)	1,298		1,298		ct / kWh
Electricity tax (variable)	60,00	42,00	42,00		EUR
Biomass subsidy (variable)	7,80	5,46	5,46		EUR
Biomass subsidy (fixed)	1,30	1,30	1,30		EUR
Renewable Energy subsidy (variable)	51,92	36,34	36,34		EUR
Renewable Energy subsidy (fixed)	10,75	10,75	10,75		EUR
Renewable Energy lump sum (fixed)	35,97	35,97	35,97		EUR
Legal fees	**167,74**	**131,83**	**131,83**	**-**	**EUR**
Total electricity costs before tax	735,34	697,92	555,71	142,20	EUR
VAT 20%	147,07	139,58	111,14	28,44	EUR
Total electricity costs for consumer	**882,41**	**837,50**	**666,86**	**170,64**	**EUR**

Savings with REC per annum	**44,91**	**EUR**

Savings with REC per annum	**5,09%**

The calculated savings of ca. 45 EUR imply a reduction of total electricity costs by ca. 5% by taking part in the REC and consuming 1/3 of the electricity from the REC.

Tab 3: A practical example of savings with local RECs (source: own calculations)

	without REC	with REC	Energy provider 70%	REC 30%	
Electricity consumption per annum	4.000	4.000	2.800	1.200	kWh
Variable consumption price (per kWh)	7,323		7,323	8,500	ct / kWh
Electricity costs (variable fee)	292,92	307,04	205,04	102,00	EUR
Electricity costs (fixed fee)	26,40	26,40	26,40		EUR
Electricity costs	**319,32**	**333,44**	**231,44**	**102,00**	**EUR**
Grid cost variable price (per kWh)	4,450		4,450	1,914	ct / kWh
Grid losses variable price (per kWh)	0,203		0,203	0,087	ct / kWh
Grid costs on consumption (variable fee)	178,00	147,56	124,60	22,96	EUR
Grid losses on consumption (variable fee)	8,12	6,73	5,68	1,05	EUR
Grid costs (fixed fee)	36,00	36,00	36,00		EUR
Metering costs (fixed fee)	26,16	26,16	26,16		EUR
Grid costs	**248,28**	**216,45**	**192,44**	**24,01**	**EUR**
Electricity tax (per kWh)	1,500		1,500		ct / kWh
Biomass subsidy (per kWh)	0,195		0,195		ct / kWh
Renewable Energy subsidy (per kWh)	1,298		1,298		ct / kWh
Electricity tax (variable)	60,00	42,00	42,00		EUR
Biomass subsidy (variable)	7,80	5,46	5,46		EUR
Biomass subsidy (fixed)	1,30	1,30	1,30		EUR
Renewable Energy subsidy (variable)	51,92	36,34	36,34		EUR
Renewable Energy subsidy (fixed)	10,75	10,75	10,75		EUR
Renewable Energy lump sum (fixed)	35,97	35,97	35,97		EUR
Legal fees	**167,74**	**131,83**	**131,83**	**-**	**EUR**
Total electricity costs before tax	735,34	681,72	555,71	126,01	EUR
VAT 20%	147,07	136,34	111,14	25,20	EUR
Total electricity costs for consumer	**882,41**	**818,07**	**666,86**	**151,21**	**EUR**

Savings with REC per annum	**64,34**	**EUR**

Savings with REC per annum	**7,29%**

In this case the savings increase because of the higher discount on the grid costs. The annual savings of ca. 64 EUR imply a reduction of total electricity costs by ca. 7,3%.

In both tables the benefits for RECs, which are only affecting the variable charges, are highlighted.

With putting the EAG into force, some terms have changed compared to the until recently applicable Ökostromgesetz. Below the terms used in this work are translated to the original terms from EAG.

Tab 4: Terms used in savings example (source: own table)

Term used	**Term according to EAG**
Electricity Tax	*Elektrizitätsabgabe*
Biomass Subsidy	*Biomasseförderbeitrag*
Renewable Energy Subsidy	*Erneuerbaren-Förderbeitrag*
Renewable Energy Lump sum	*Erneuerbaren Förderpauschale*

2.3 Actors in energy communities

In Europe, a regulatory shift away from feed-in tariffs can be observed, which provided financial certainty to an energy community in the past towards a more market-oriented design. Energy communities were thus incentivized to adapt to this changing regime (Bauwens et al., 2016).

In this new framework the interests of different actors often conflict, which leads to challenges when designing an energy community. Typical actors with conflicting interests are energy communities on the one side and energy service providers, grid operators or governments on the other side (Koirala et al., 2016).

According to Gjorgievski et al. (2021) one can differentiate between different actors within an energy community as outlined in the below figure.

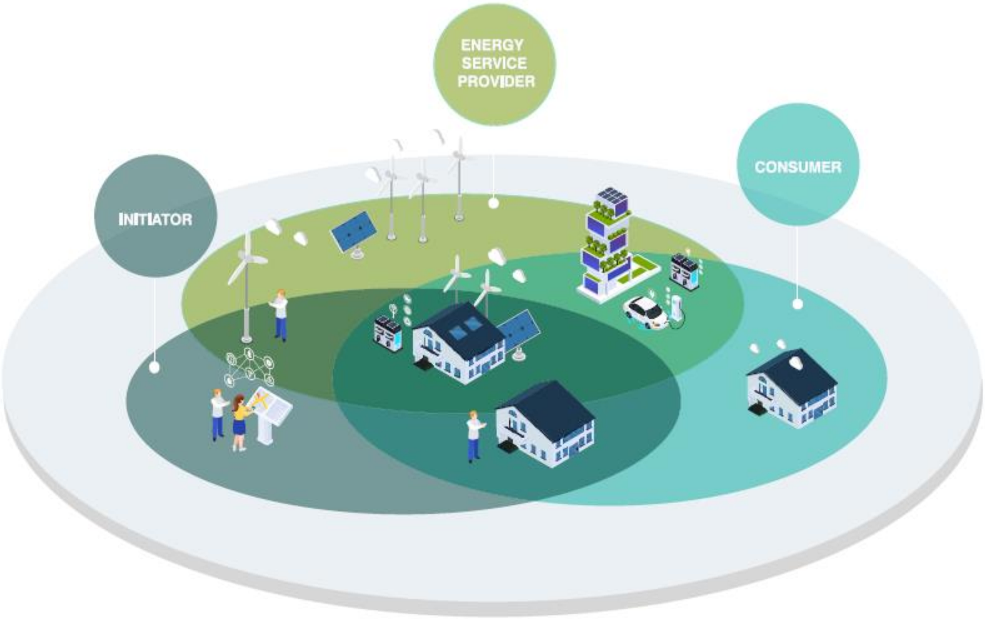


Fig 4: Different actors as part of an energy community (Gjorgievski et al., 2021)

2.3.1 Consumer

A consumer benefits from an energy commodity or service provided by another actor of energy community. This benefit can be threefold, environmental, social and economic. A consumer typically does not own any generation or storage unit.

2.3.2 Energy service provider

Energy service providers typically provide energy related services such as generation, distribution, or storage of energy. Energy service providers may also own and use infrastructure related to the previously mentioned services. When prosumers are net generators, they can also be subsumed as energy service providers as they act at the intersection of consumers and energy service providers.

2.3.3 Initiator

Initiators play a crucial role when setting up an energy community as they set in motion the organization of an energy community. Initiators might or might not benefit from the community's energy services.

The role of initiators can also be played by consumers and prosumers.

2.4 Classification of energy communities

In literature a range of features are used to categorize energy communities.

Tab 5: Classification of energy communities in literature (Gjorgievski et al., 2021)

Feature	**Classification**	**Reference**
Purpose	• Single purpose • Multi purpose	Moroni et al. (2019)
Location	• Place-based • Non-place-based	Moroni et al. (2019)
Organization	• Centralized • Decentralized • Distributed	Gui and MacGill (2018)
Activity	• Energy management • energy generation • self-consumption	Verkade and Höffken (2019)
Legal entities	• Energy cooperatives • Limited partnerships • Community trusts and foundations • Housing associations	Caramizaru and Uihlein (2020)

	• Nonprofit consumer-owned enterprises • Public private partnerships • Public utility companies	
Energy grid	• On-grid/Off-grid • Within a housing company • Crossing property boundaries • Distributed energy community	Caramizaru and Uihlein (2020) Pahkala et al. (2018)

2.5 Enabling and disabling factors for energy communities

2.5.1 Non-technical enabling factors

According to Bauwens et al. (2016) non-technical enabling factors can be found in environments with rich financial opportunities, a proper legislative framework and active local initiators. This is necessary to compensate for the inability of a community to compete with professional market actors, who are primarily active in the energy markets (Gjorgievski et al., 2021).

Usually, a smaller group of actors – typically equipped with technical and financial knowledge – will initiate the formation of a community, as it is not expectable that every citizen provides equal time and effort (Koirala, et al., 2018).

Securing reliable demand, subsidy models, risk guarantees, and various revenue streams are affected by the economic development of a country according to Williams et al. (2015).

Dóci et al. (2015) identified three factors for supporting the scaling up of energy communities: (1) generic rules and lessons at the system level, (2) support from powerful actors, (3) heterogeneity in terms of actors, motivation and technologies.

2.5.2 Technical enabling factors

The technical infrastructure depends on which actors are part of an energy community. If an energy community consists solely of consumers, almost no enabling technologies are required.

Access to a reliable power grid is a basic enabling technology but can pose a challenge in developing countries (Williams et al., 2015).

Energy communities in developed countries usually use a more advanced ICT infrastructure. According to Tushar et al. (2020), most systems implemented by energy communities require enabling technologies in both the physical and virtual layers.

For sharing energy within a community, a grid connection and an advanced metering infrastructure including smart meters, a network and a communication system are required by every actor. The smart metering infrastructure consists of advanced meter reading, time-of-use pricing and a data management system (Kabalci, 2016).

According to Jogunola et al. (2018) certain criteria have to be met concerning the latency, throughput, reliability and security of different elements in the communication network.

The virtual layer enforces the contracts and interactions. It consists of an information system – often enabled by ledger technologies – market operation, pricing mechanisms and an energy management system, which controls the elements in the physical layer (Gjorgievski et al., 2021).

2.5.3 Disabling factors

Actors in an energy community need to overcome various challenges, which can be distinguished as internal and external barriers (Mirzania et al., 2019).

Typical external barriers can be of technical, environmental and institutional nature.

Technical barriers can be linked to limitations of the distribution networks capacity. Those limitations materialize based on the intermittency of distributed renewable generation, low energy efficiency of end users of a mismatch between local supply and demand (Koirala et al., 2016).

Environmental barriers can be related to the spatial needs, land use and waste generation depending on the specific renewable technology in use (van Zalk and Behrens, 2018).

Institutional barriers can materialize in the form of poorly defined legislative frameworks, a discrimination against small actors in the energy sector or even a structural resistance to grassroots initiatives (Roberts et al., 2019).

According to Brummer (2018) a saturation effect could be noted in Germany, as all the interested consumers were already part of energy communities or because the most promising locations for new energy community projects had already been taken.

Internal barriers can be linked to financing. High investment cost of renewable infrastructure and at the same time a lack of access to financing can pose a considerable barrier. Additionally, a lack of motivated local initiators can be a barrier as well (Koirala et al., 2018).

According to Oteman et al. (2014) can a lack of expertise within a energy community or significant dependence on outside support reduce the resilience of such a community.

2.6 Challenges for energy communities

A lot of research has been done on the benefits of energy communities. The advantages of RECs under the EAG have already been discussed. However, Abada et al. (2020) discuss how inadequate grid tariffs may lead to excess adoption of energy community business models. They identify two main challenges:

The first challenge concerns the allocation of the benefit that leads to a stable coalition among community members. Stability can be reached if the coalition generates value that can be shared in a satisfactory way among its members.

The second challenge is related to the origin of the benefit itself. This can lead to externalities that need to be accounted for. Not paying grid costs for the self-consumed energy creates value for the community but at the same time lead to a revenue shortfall for the grid operator. Low-contributing consumers result in lower income for the distribution companies which in turn leads to tariff increases, because the costs of maintaining the grid still incur at the distribution company. Higher tariffs on the other hand lead to more consumers investing in PV and taking part in an energy community, thus creating a snowball effect.

Abada et al. (2020) conclude that it is dependent on the policymakers' motivations if they deem the snowball effect beneficial. This might be the case when having a policy goal to increase PV and battery installations. However, if communities make up a too large share of the consumer base, investments in those technologies might be too high and policymakers might be pushed to change the tariff structure. The authors suggest for the former case a capacity-based or energy-based tariff model. In the latter case they suggest an increase in the per-connection tariff component.

2.7 Impact analysis of energy communities

2.7.1 Environmental impact

According to Koirala et al. (2018) environmental concerns are one of the most important drivers influencing a consumer's willingness to take part in an energy community.

Gjorgievski et al. (2021) reviewed literature based on reported environmental impacts. The authors concluded that in most cases CO2 emissions and greenhouse gas (GHG) emissions were reported. Only occasionally life cycle emissions, refrigerant emissions and particulate matter was reported.

2.7.2 Technical impact

Energy communities can improve the autonomy, increase the reliability and reduce the overall energy consumption (Gjorgievski et al., 2021). According to the authors the following indicators were used to discuss the technical impacts of local energy projects: Self-consumption rate and self-sufficiency rate in most of the cases, primary energy in some cases and only occasionally loss-of-load probability, load match index, and electricity exports.

2.7.3 Social impact

In contrast to environmental and technical impact analyses, the evaluation of social impacts lacks in many cases a quantitative framework. Gjorgievski et al. (2021) found in their review the following social benefits without a quanitifyable framework: enhanced social cohesion, improved energy literacy, development of social networks, promotion of global partnerships and reduced energy poverty.

Kumar et al. (2019) propose the following key performance indicators: public acceptance, human development index, health issues, universal education, gender equality, and the creation of jobs.

2.8 Energy communities’ role in delivering energy justice

RECs can play a major part in the energy transition. Through their collective organization, RECs engage with local households and encourage the participation of local citizen (Walker and Devine-Wright, 2008). Moreover, they raise social acceptance for the energy transition (Baxter et al., 2013). RECs can also enable community regeneration and autonomy (Callaghan and Williams, 2014).

Hanke et al. (2021) discuss the role of RECs in overcoming energy-related injustices. Energy vulnerable groups are often excluded from shaping the energy transition (Simcock et al., 2017).

Theoretically, RECs should be able to engage with energy vulnerable groups and mitigate energy poverty, e.g. by providing lower tariffs and increased energy efficiency (Hanke & Lowitzsch, 2020).

European legislation also considers these elements in the recast of the renewable energy directive (RED II). There, also the social role of RECs in the energy transition is emphasized: “opportunities for renewable energy communities to advance energy efficiency at household level and (…) fight energy poverty”.

RED II links the enabling framework “to promote and facilitate the development of renewable energy communities” with the obligation to ensure the participation of all “consumers, including those in low-income or vulnerable households” At the same time, RED II does not give any details on how to achieve a REC’s social role in practice (Hanke et al., 2021).

McGee and Greiner (2019) found out that currently only some social groups have the means to participate in RECs and benefit from the transition to clean energy. Those means to participate could be economic capital, time or know-how.

In their research, Hanke et al. (2021) conclude that RECs actively contributing to energy justice by engaging with vulernable and underrepresented groups and providing access to beneficial services to alleviate energy poverty remain the exception. Although they found willingness among RECs, RECs express restrictions and challenges, limiting their ability to address energy justice.

3 Description of estimation model

In the previous part of this work the concept of energy communities was introduced. Also, the legal framework in Europe and Austria and associated benefits were discussed in detail.

Building on that theoretical foundation, the next chapter describes how representatives of municipalities can estimate their potential of starting an REC. The following model explains which parameters are important for roof-top PV electricity generation and how those parameters can be used to estimate electricity generation and demand profiles.

Thus, the next chapter can be seen as a manual for local authorities to find out if a REC could work from a technical perspective.

The core objective of this model is providing a tool for municipalities to estimate the potential of establishing a REC according to EAG with two major steps:

Firstly, the user can estimate the electricity generation potential of typical communal buildings via rooftop PV according to their roof type and orientation.

In a second step the model will estimate the electricity self demand based on benchmarking ratios derived from the energy bookkeeping of typical municipalities in Lower Austria.

The surplus of generation potential deducted by the own demand gives the amount of electricity that can be used to establish an energy community.

In the final part of the model covers the usage of the electricity surplus and explores how many households could be supplied by the generated electricity.

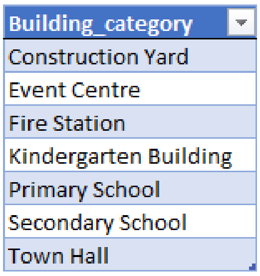
The model is set up for an easy usability by local authorities. The model calculation is implemented using a common spreadsheet software. For some parameters, the user can select from a drop-down menue, for others absolute values have to be entered. The result of each input is directly reflected in the graphs available in each section of the model.

3.1 Estimating the generation potential

3.1.1 Building categories

As a starting point, seven different building categories were defined. Those categories represent the seven most frequent communal buildings. The categories were chosen based on the energy bookkeeping of communities located in Lower Austria. A list of the building categories used in this model is illustrated below.

Tab 6: Summary of building categories (source: own model)

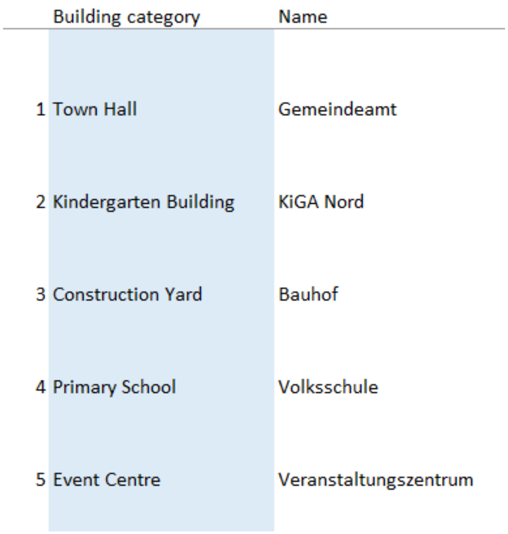


Building_category
Construction Yard
Event Centre
Fire Station
Kindergarten Building
Primary School
Secondary School
Town Hall

For reasons of better keeping track, the model is currently limited to ten buildings per community but can easily be expanded to a larger number of buildings.

To start with the estimation model, a building category has to be chosen from a dropdown menue. For means of easier traceability of a building, especially in the case of more than one building per category within a community, a name can be added to each building.

Tab 7: Example of building categories and distinct name per building (source: own model)



	Building category	Name
1	Town Hall	Gemeindeamt
2	Kindergarten Building	KiGA Nord
3	Construction Yard	Bauhof
4	Primary School	Volksschule
5	Event Centre	Veranstaltungszentrum

3.1.2 Roof types

According to Bayod-Rújula et al. (2011) the characteristics of the roof, i.e. slope, azimuth and available surface determine the PV electricity generation performance of a sloped roof. On flat roofs the optimal positioning of the modules as well as the optimal inclination angle can be fixed with supporting structures. Concerning the optimum use of the available surface area, the distance between the module rows must be considered to avoid shadowing of modules.

Also, Hachem et al. (2012) found that the rooftop shape has a significant effect on the annual electricity generation of the rooftop PV system, because various design parameters are determined by the rooftop shape. The rooftop shapes of the rooftop PV system are generally categorized into (i) flat roof and (ii) gable roof.

For this model the categorization was extended by one more roof type, a shed roof. To proceed in the modelling, a selection has to be made between the three most common roof types in Lower Austria:

(i) a flat roof, which is for example typically used in newly built kindergarten buildings,
(ii) a shed roof, which often can be found on construction yard buildings, and
(iii) a gabled roof, which is often used in older buildings, e.g. town halls or fire stations.

Pictograms of the three roof types available for selection in the model can be found below.

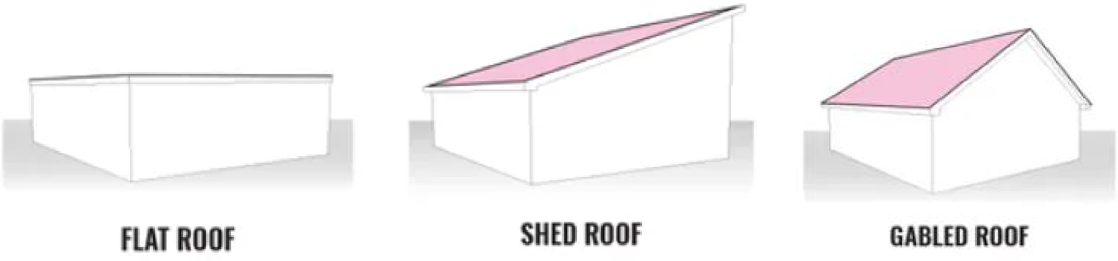


Fig 5: Different roof types in the model (Owens Corning, 2021)

Tab 8: Previous example supplemented with roof type (source: own model)

	Building category	Name	Roof type
1	Town Hall	Gemeindeamt	Gable
2	Kindergarten Building	KiGA Nord	Shed
3	Construction Yard	Bauhof	Flat
4	Primary School	Volksschule	Shed
5	Event Centre	Veranstaltungszentrum	Gable

3.1.3 Orientation

Dependent on the choice of roof type, the orientation of the roof can be selected. The orientation, also referred to as azimuth, is of great importance for calculating the generation potential of a building as it is a key parameter in calculating the solar yield (Bayod-Rújula et al., 2011).

According to Hachem-Vermette (2020), the orientation affects the solar potential in two ways: (1) the amount of generation and (2) the time of peak generation.

On an annual basis, the highest energy yield is associated with south facing PV systems. A deviation of the orientation of the system from south by up to 30° east or west, leads to an approximate reduction in annual electricity generation of up to 5%. A deviation of 60° east or west results in a reduction of up to 12% (Hachem-Vermette, 2020).

Dependent on the roof type, the orientation of a roof can have more than one direction. For a gabled roof two opposite directions have to be taken into account. A shed roof can be directed in one direction.

For a flat roof the orientation of the building is not of major importance as the modules can be directed in either direction on the roof. In this model it is suggested to have an East/West orientation of modules on flat roofs.

According to Yang et al. (2020), south-facing PV modules face shading issues, which are illustrated below. In scenario (a) the shading effect is minimized by an increase in row distance. The distance is calculated to avoid mutual shading on winter solstice at noon. In scenario (b) the combination of tilt angle and row distance is optimized to have a higher potential installed capacity due to smaller inter-row distance, and lower shading losses using smaller tilt angles.

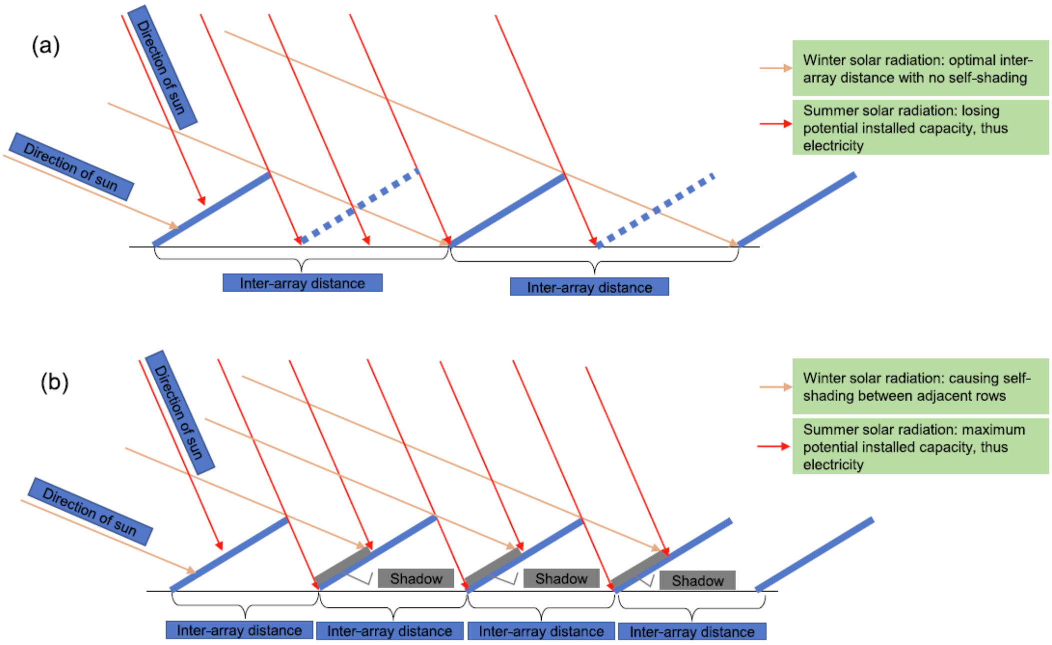


Fig 6: Two different scenarios of row distance causing different inter-row shading effects (Yang et al., 2020)

A south-facing PV system is generally suitable for maximizing the electricity generation, although the effects of inter-row shading exist.

In order to reach an effective electricity production with less shading, an East/West orientation with low tilt angle is suggested (Yang et al., 2020).

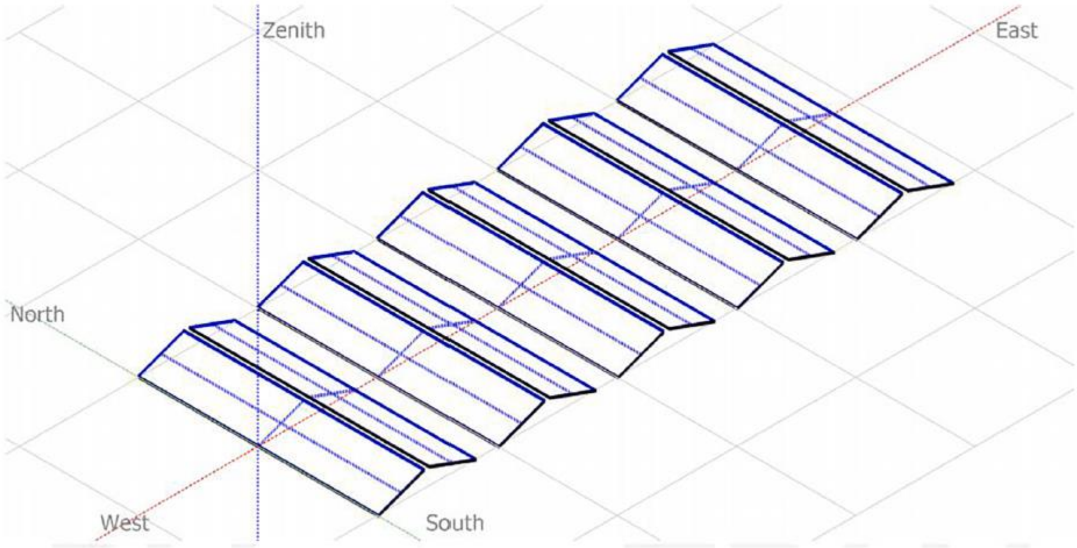


Fig 7: Scenario with East/West orientation and low tilt angle (Yang et al., 2020)

Such an East/West orientation generates less electricity per installed power compared to south-facing systems, because the modules receive lower radiation. On the other hand, such an installation could be packed more tightly together on flat roofs compared to south-oriented systems that require further space to avoid mutual shading. Therefore, an East/West orientation leads to to maximum coverage of roof area with insignificant shading (Yang et al., 2020).

Another advantage of an East/West orientation is a better distribution of electricity generation over the day. This is especially important if the consumption of the electricity is tied to morning and evening hours and not peaking at noon. Therefore, an East/West orientation matches the consumption profile of typical households better than a South-facing system.

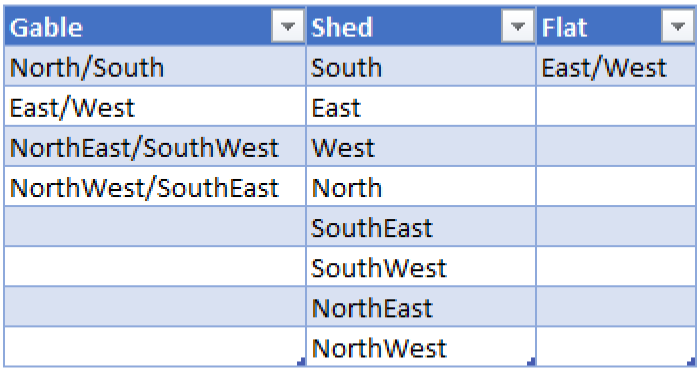
In case of an adverse building orientation, an East/West orientation of modules could be not economic, because of loosing too much space on the corners. Here, a module allocation that utilizes the maximum roof space could result in deviating more in direction South.

The model also accounts for these differences. For gabled roofs, the orientation can be selected in pairs only. For shed roofs, every orientation can be selected. In case of a flat roof, an East/West direction is the only available choice as the best possible distribution of electricity generation over the day is targeted.

For means of a more accurate estimate, not only the four cardinal directions, but also the intercardinal directions can be chosen.

All orientations possible in the model categorized by roof type are illustrated below.

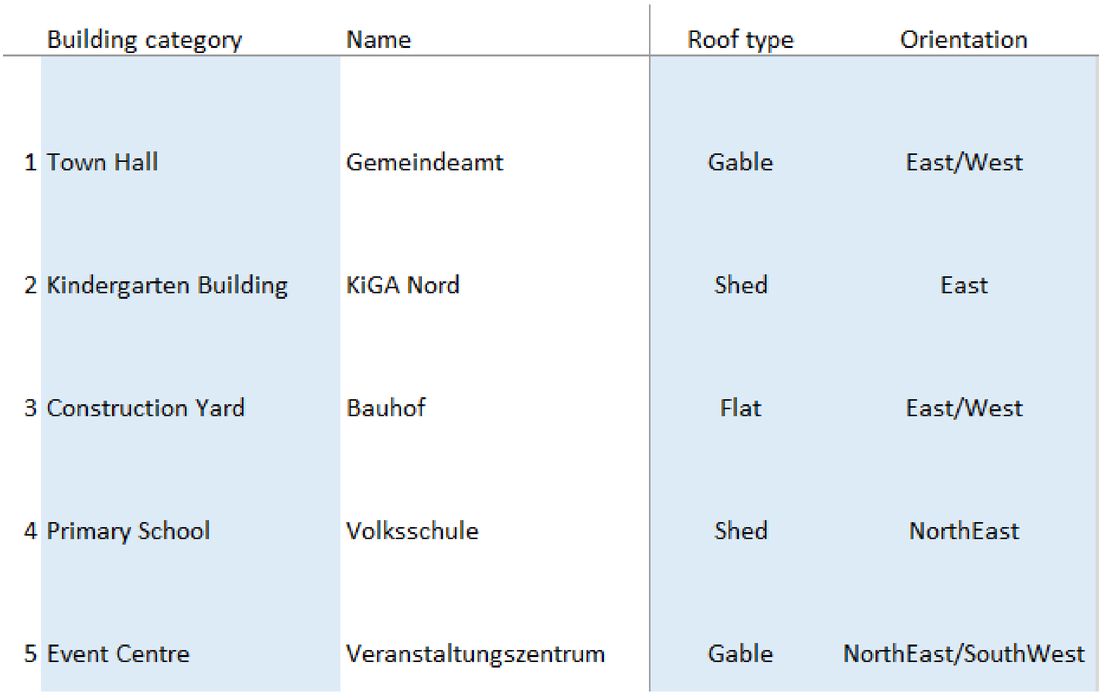
Tab 9: Possible PV orientation per roof type (source: own model)



Gable ▾	Shed ▾	Flat ▾
North/South	South	East/West
East/West	East	
NorthEast/SouthWest	West	
NorthWest/SouthEast	North	
	SouthEast	
	SouthWest	
	NorthEast	
	NorthWest	

How the orientation is factored into the model is illustrated below.

Tab 10: Previous example supplemented with orientation (source: own model)



	Building category	Name	Roof type	Orientation
1	Town Hall	Gemeindeamt	Gable	East/West
2	Kindergarten Building	KiGA Nord	Shed	East
3	Construction Yard	Bauhof	Flat	East/West
4	Primary School	Volksschule	Shed	NorthEast
5	Event Centre	Veranstaltungszentrum	Gable	NorthEast/SouthWest

3.1.4 Roof area

In a next step the theoretical roof area needs to be determined. To estimate the theoretical roof area, the length and width of the roof are multiplied. In case of gabled roofs, the standard formula needs to be adjusted to take into account both areas of the gabled roof.

$$A_{th} = L * W \qquad \text{(Equ. 1)}$$

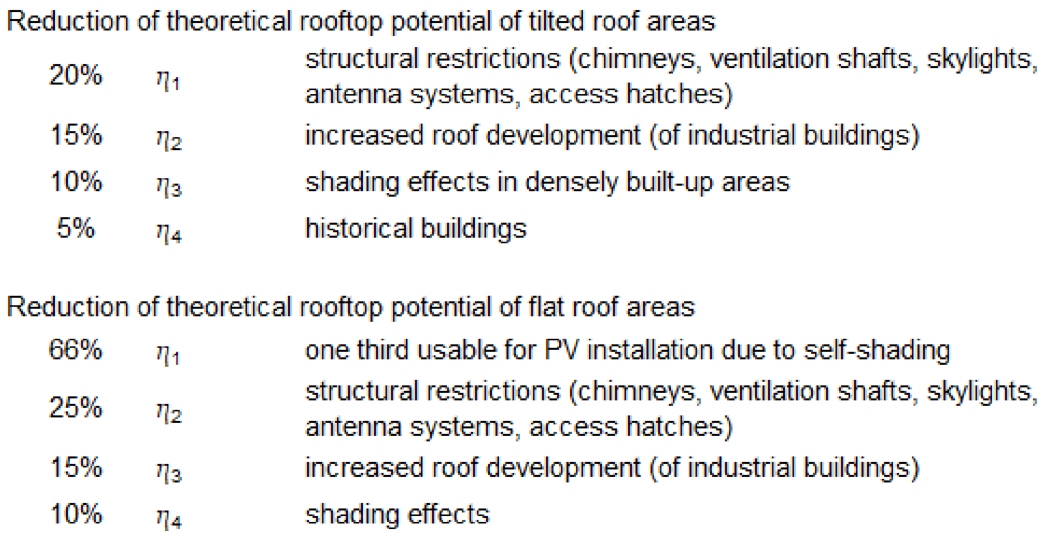
$$A_{th\_gable} = L * W * 2 \qquad \text{(Equ. 2)}$$

A_{th} = Theoretical roof area [qm]
A_{th_gable} = Theoretical roof area for gabled roofs [qm]
L = Length [m]
W = Width [m]

Based on the theoretical rooftop area, the actually available area for a PV system is determined by accounting for various diminishing factors.

Fina (2020) gives a good overview of different diminishing factors:

Tab 11: Determination of technical rooftop area (Fina, 2020)



Reduction of theoretical rooftop potential of tilted roof areas		
20%	η_1	structural restrictions (chimneys, ventilation shafts, skylights, antenna systems, access hatches)
15%	η_2	increased roof development (of industrial buildings)
10%	η_3	shading effects in densely built-up areas
5%	η_4	historical buildings
Reduction of theoretical rooftop potential of flat roof areas		
66%	η_1	one third usable for PV installation due to self-shading
25%	η_2	structural restrictions (chimneys, ventilation shafts, skylights, antenna systems, access hatches)
15%	η_3	increased roof development (of industrial buildings)
10%	η_4	shading effects

Most of the diminishing factors listed above range between 10 – 25%. The 66% reduction related to self shading for flat roofs seem not to reflect the latest developments.

To account for roof area that is not available for PV modules, the theoretical roof area is multiplied by a diminishing factor to derive the useable roof area.

$$A_{useable} = A_{th} * (1 - F_D) \tag{Equ. 3}$$

$A_{useable}$ = Usable roof area [qm]
A_{th} = Theoretical roof area [qm]
F_D = Diminishing factor [0-1]

Based on the above listed various diminishing factors, in the model an average diminishing factor of 15% is fixed.

Tab 12: Example with calculated theoretical and usable roof area (source: own model)

	Building category	Name	Length [m]	Width [m]	Theoretical roof area [qm]	Useable roof area [qm]
1	Town Hall	Gemeindeamt	10	8	160	136
2	Kindergarten Building	KiGA Nord	10	8	80	68
3	Construction Yard	Bauhof	15	10	150	128
4	Primary School	Volksschule	20	20	400	340
5	Event Centre	Veranstaltungszentrum	15	15	450	383

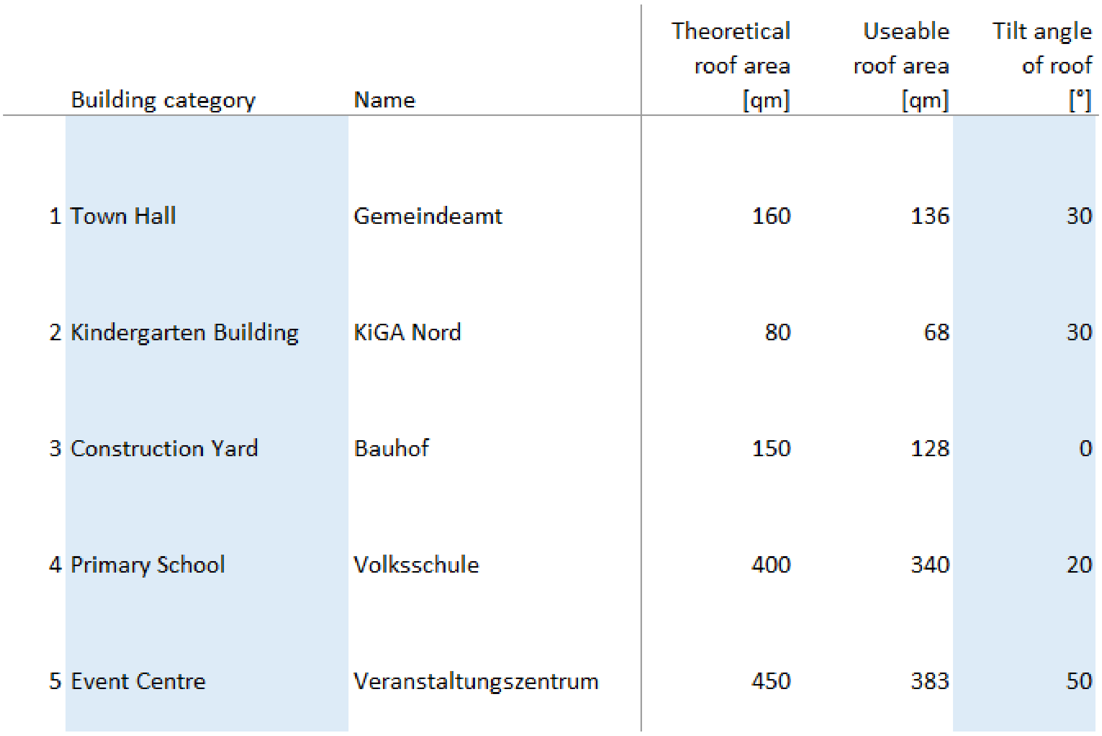
3.1.5 Tilt angle of the roof

As a next step, the tilt angle or slope of the roof as an approximation for the slope of the mounted PV modules has to be considered.

The tilt angle of the roof is the angle between the normal to the surface and the vertical direction. The tilt angle has an impact on the amount of solar radiation captured by the PV modules and thus on the total energy generation. Steeper tilt angles lead to better performance in winter months, and reduced performance in summer months. For mid-latitude locations, a tilt angle ranging between 30° and 50° does not affect the annual electricity generation significantly. A tilt angle of 60°, compared to 45°, leads to a reduced electricity generation of around 7% per annum and of 16% in June, while increasing the generation in December by approximately 6%. (Hachem-Vermette, 2020)

In the model the tilt angle can range between 0 and 90°. Typically, a value between 20 and 40° is suitable for gable and shed roof, for flat roofs PV modules are typically mounted using a slope between 10° and 20°.

Tab 13: Example with tilt angle of roof (source: own model)



	Building category	Name	Theoretical roof area [qm]	Useable roof area [qm]	Tilt angle of roof [°]
1	Town Hall	Gemeindeamt	160	136	30
2	Kindergarten Building	KiGA Nord	80	68	30
3	Construction Yard	Bauhof	150	128	0
4	Primary School	Volksschule	400	340	20
5	Event Centre	Veranstaltungszentrum	450	383	50

3.1.6 Irradiation

The area of Lower Austria is located in the North East of Austria, between 47,5° and 49° of latitude. In the map below the area is framed in light blue. According to the Global Solar Atlas 2.0 of World Bank Group, the global horizontal irradiation ranges between 1250 kWh/qm in the very east of the state to 1150 kWh/qm in the west. As a basis for the calculations in the model 1200 kWh/qm was assumed.

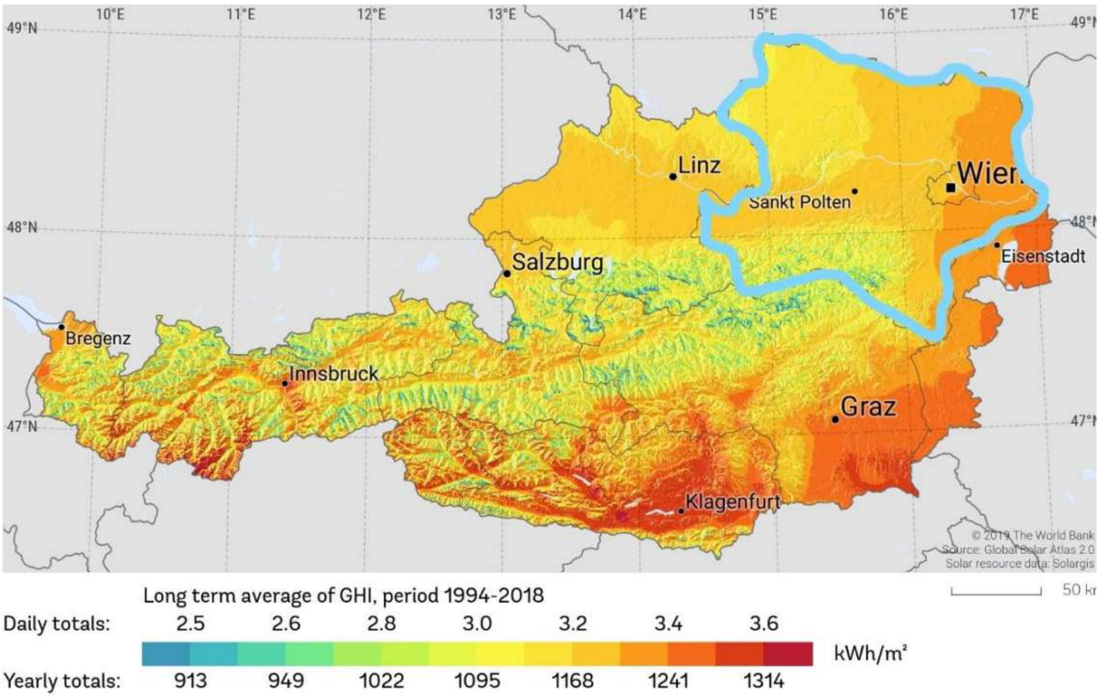


Fig 8: Global horizontal irradiation in Austria (Global Solar Atlas 2.0, 2021)

Considering the tilt angle of the PV system and its orientation, this leads to an actual irradiation factor between 0% to 100%. The irradiation factors were derived from Matthiss et al. (2015) who used Merklingen-Widderstall in the South of Germany as a reference location. Merklingen-Widderstall is located around 48,5° of latitude, which makes this orientation map suitable for the area of lower Austria as well.

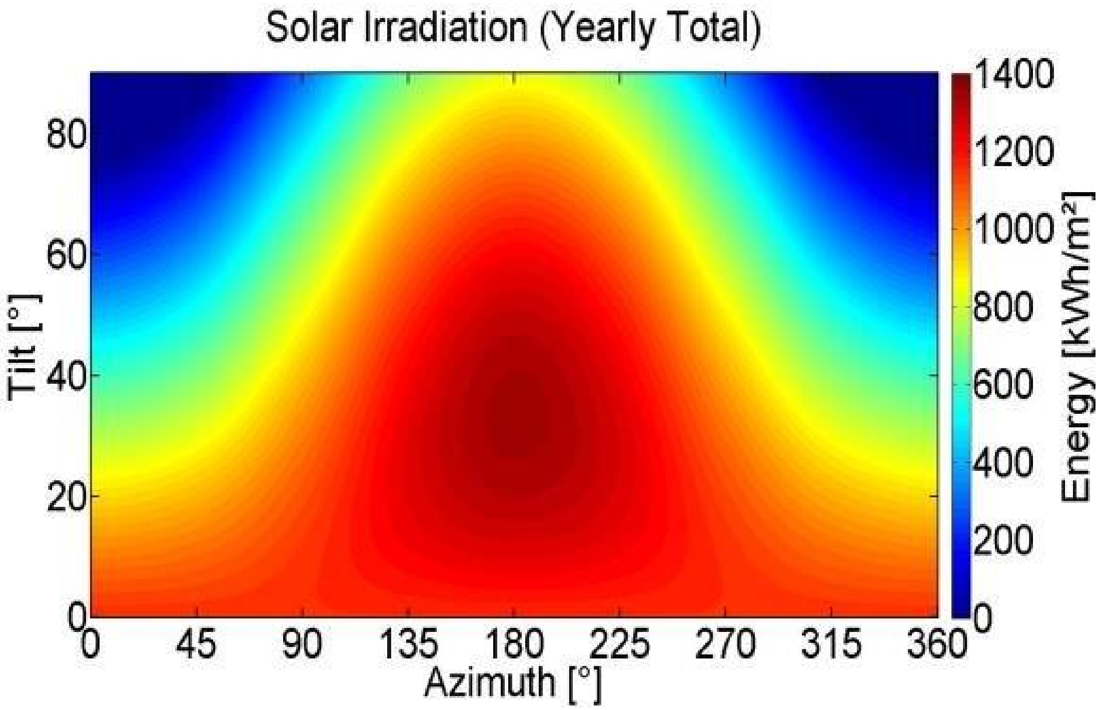
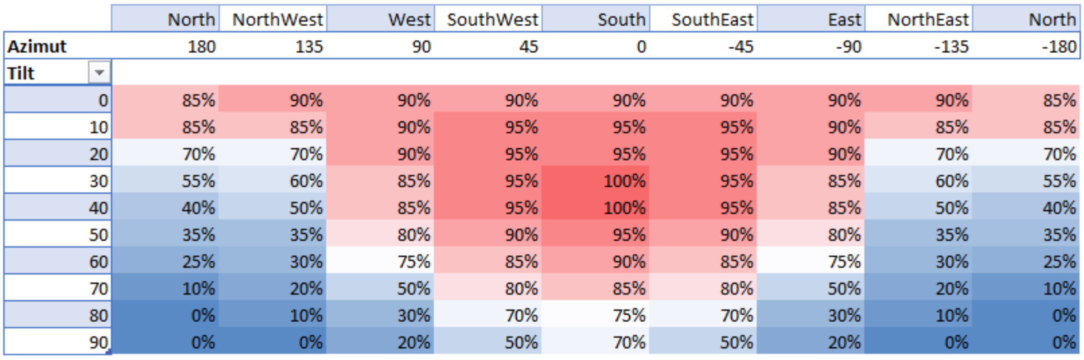


Fig 9: Solar Irradiation dependent on tilt and orientation (Matthiss et al., 2015)

On the basis of this orientation map, a table with irradiation factors was compiled for shed and flat roofs as well as for gable roofs. A south orientation with a tilt angle of 30 - 40° lead to the highest irradiation factor of 100%. This factor decreases with the change of tilt or orientation or both. The lowest irradiation factor would be realized in a northbound orientation with a very steep tilt of 80 - 90°.

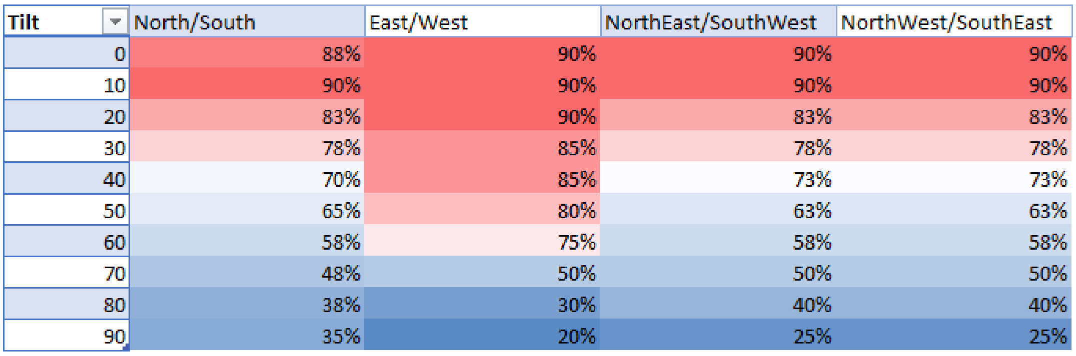
Tab 14: Irradiation factor map for shed and flat roofs (source: own model)



	North	NorthWest	West	SouthWest	South	SouthEast	East	NorthEast	North
Azimut	180	135	90	45	0	-45	-90	-135	-180
Tilt									
0	85%	90%	90%	90%	90%	90%	90%	90%	85%
10	85%	85%	90%	95%	95%	95%	90%	85%	85%
20	70%	70%	90%	95%	95%	95%	90%	70%	70%
30	55%	60%	85%	95%	100%	95%	85%	60%	55%
40	40%	50%	85%	95%	100%	95%	85%	50%	40%
50	35%	35%	80%	90%	95%	90%	80%	35%	35%
60	25%	30%	75%	85%	90%	85%	75%	30%	25%
70	10%	20%	50%	80%	85%	80%	50%	20%	10%
80	0%	10%	30%	70%	75%	70%	30%	10%	0%
90	0%	0%	20%	50%	70%	50%	20%	0%	0%

In case of gable roofs, two opposite roof areas have to be taken into account when estimating the irradiation factor. For this reason, the individual irradiation factors of the two opposite directions (from above) were combined to derive an irradiation factor for the gable roof. For example, the irradiation factor of NorthEast for a tilt of 10° gives 85%; the opposite direction of SouthWest for the same tilt gives 95%; this results in an average combined irradiation factor for a tilt of 10° of 90%.

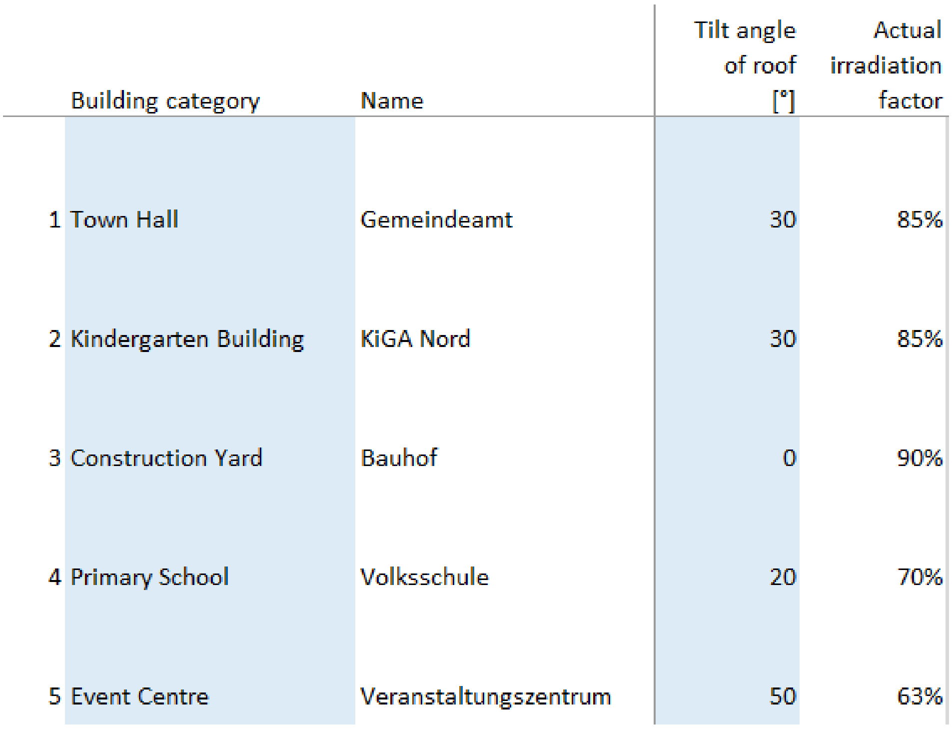
Tab 15: Irradiation factor map for gable roofs (source: own model)



Tilt	North/South	East/West	NorthEast/SouthWest	NorthWest/SouthEast
0	88%	90%	90%	90%
10	90%	90%	90%	90%
20	83%	90%	83%	83%
30	78%	85%	78%	78%
40	70%	85%	73%	73%
50	65%	80%	63%	63%
60	58%	75%	58%	58%
70	48%	50%	50%	50%
80	38%	30%	40%	40%
90	35%	20%	25%	25%

In the model the actual irradiation factor is selected from the above illustrated factor maps based on tilt and orientation.

Tab 16: Example with actual irradiation factor (source: own model)



	Building category	Name	Tilt angle of roof [°]	Actual irradiation factor
1	Town Hall	Gemeindeamt	30	85%
2	Kindergarten Building	KiGA Nord	30	85%
3	Construction Yard	Bauhof	0	90%
4	Primary School	Volksschule	20	70%
5	Event Centre	Veranstaltungszentrum	50	63%

3.1.7 Performance Ratio

The performance ratio (PR) is a globally accepted indicator to judge the performance of grid connected PV plants. The PR is the proportion of energy that is available for feeding into the grid minus the energy lost due to various environmental factors like soiling, degradation, etc., and energy consumed in the operation process (Khalid et al., 2016).

The actual energy generated by the PV plant in relation to its expected energy with reference to its nameplate rating is represented by the PR. Thus, the PR can be interpreted as an indicator of losses resulting from different sources like inverter problems, wiring, shading, cell mismatch, reflection, outages, module temperature, etc. (Dierauf et al., 2013).

Khalid et al. (2016) give an overview on PR value ranges and their development. In the 1990s a PR typically ranged between 0,65 - 0,70. In the 2000s the PR increased to 0,75 - 0,80. Nowadays a PR reaches values of 0,80 - 0,90. Those value ranges are also illustrated below.

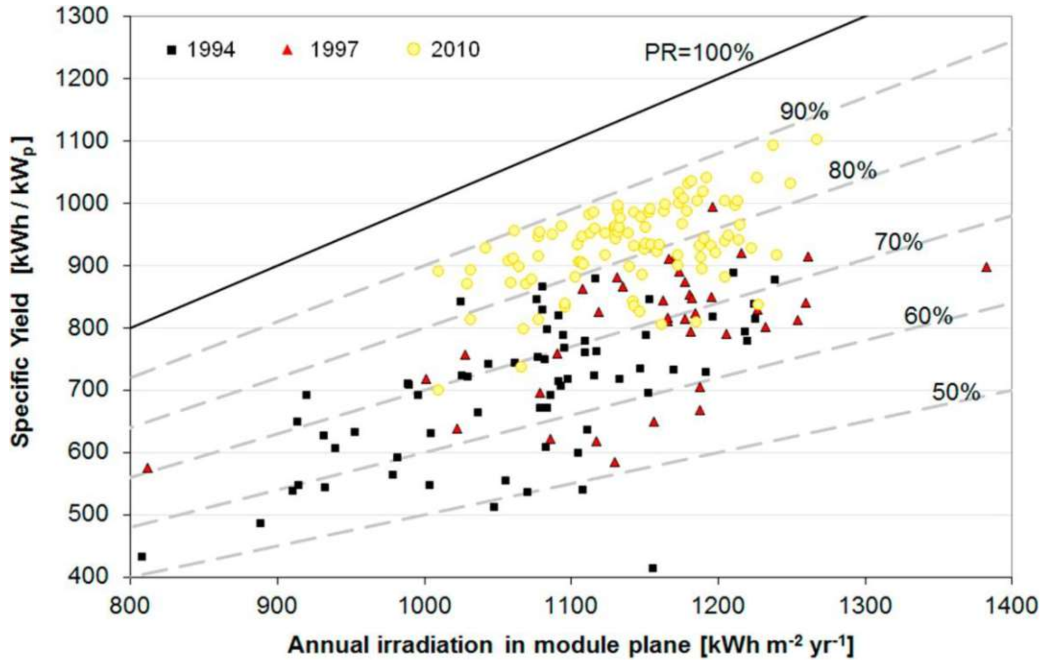


Fig 10: PR values measured by Fraunhofer ISE (Reich et al., 2012)

For this model a PR of 85% is assumed as this is the midpoint of today's bandwith.

The above-mentioned losses that are the basis for the PR are more of general nature and affect most rooftop PV plants to a similar extent.

To account for permanent issues effecting one specific building or PV system, an additional correction factor is introduced to this model. This is to account e.g. for permanent shadings of parts of the roof or bigger areas of the roof that are not available for mounting a PV system (e.g. because of ventilation systems installed). This correction factor is optional and can be chosen by the user of the model on a discretionary basis.

3.1.8 Efficiency of PV cells

The efficiencies of PV cells are dependent on the technology used. The National Renewable Energy Laboratory (NREL) is giving a valuable overview on the best research-cell efficiencies over time. The results are combined according to the family of semiconductors used. As crystalline silicon cells are the economically most attractive cells and therefore the most widely spread cells on European roofs, the below graph is highlighting those cell efficiencies.

The measurements for entries in this chart must be read with respect to Standard Test or Reporting Conditions as defined by the global reference spectrum for flat-plate devices and the direct reference spectrum for concentrator devices as listed in standards IEC 60904-3 edition 2 or ASTM G173. The reference temperature is 25°C, and the area is the cell total area, or the area defined by an aperture (NREL, 2021).

The best research-cell efficiencies for multicrytalline cells are indicated at 23,3%. As this number was measured under standard test conditions, for current applications and for this model an average efficiency of 20% is assumed.

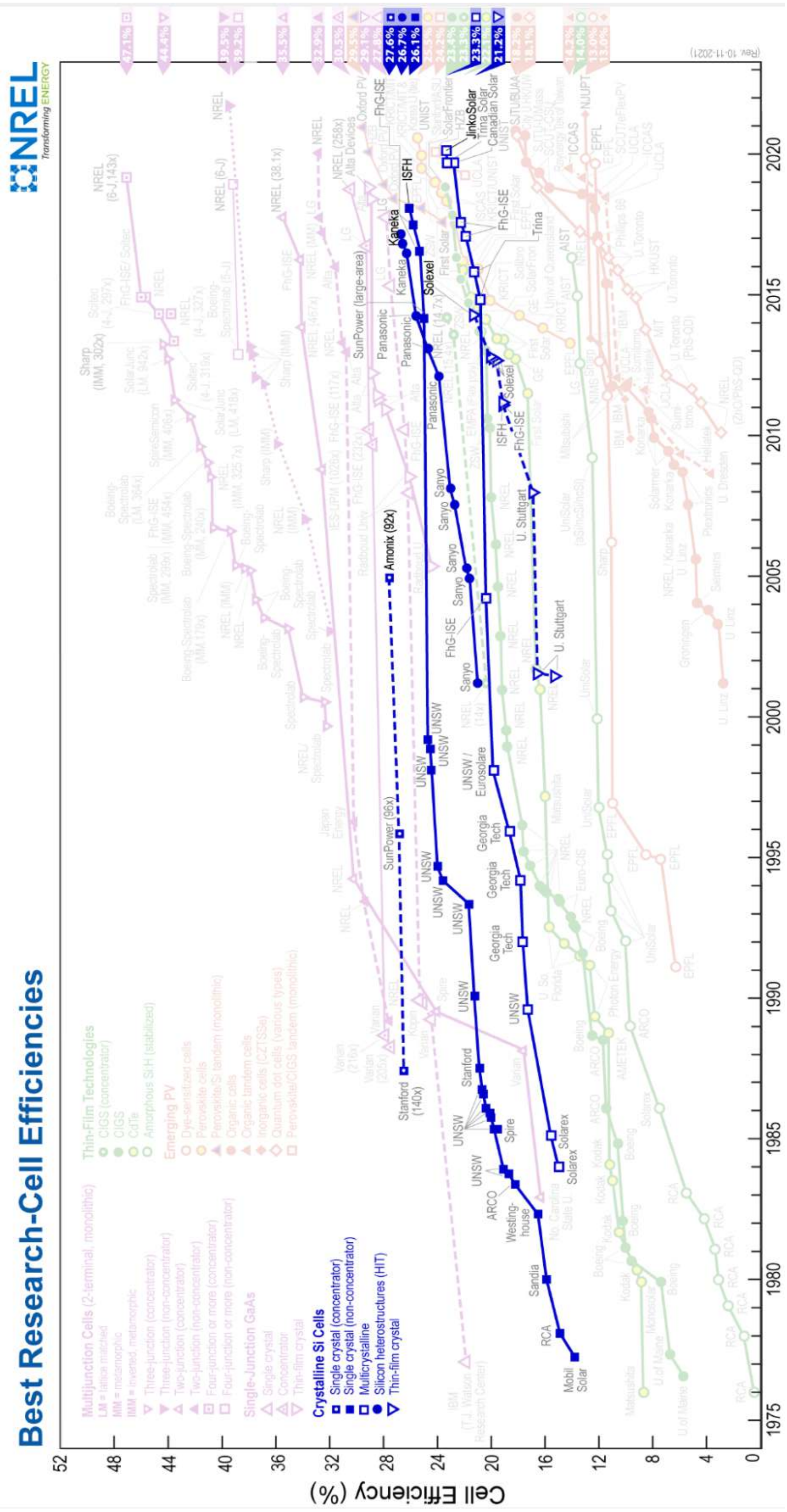


Fig 11: Best research-cell efficiencies (NREL, 2021)

3.1.9 Calculation of energy generation

Based on Ping et al. (2020) and the assumptions and estimates detailed above the estimated annual electricity generation is calculated as follows:

$$EG_{PV} = \eta * A_{useable} * PR * avg\_irr * (1 - F_C) \qquad \text{(Equ. 4)}$$

EG_{PV} = Estimated annual electricity generation from PV [kWh]
η = Efficiency of rooftop PV modules [%] (see chapter 3.1.8)
$A_{useable}$ = Usable roof area [qm] (see chapter 3.1.4)
PR = Performance Ratio [%] (see chapter 3.1.7)
avg_irr = actual annual average irradiation on tilted panels [kWh/qm.a] (see chapters 3.1.5 and 3.1.6)
F_C = correction factor [%], i.e. % of useable roof area that is constantly not useable (see chapter 3.1.7)

In this model the following fixed default values for the parameters above are suggested:

η = 20%; PR = 85%; avg_irr =1.200 kWh/qm.a
$A_{useable}$ and F_C are varying dependent on the specific building.

The total estimated annual electricity generation is the sum of the estimated annual electricity generation of all buildings.

$$Total\ EG_{PV} = \sum_{n=1}^{N} EG_{PV}\,(\mathrm{n}) \qquad \text{(Equ. 5)}$$

$Total\ EG_{PV}$ = Total estimated annual electricity generation [kWh]
$EG_{PV}\,(\mathrm{n})$ = Estimated annual electricity generation per building n [kWh]
n = building count
N = total number of buildings

3.1.10 Monthly breakdown of energy generation

In order to have a better understanding of how the annual electricity generation is distributed over the year on a monthly level, a monthly generation profile is illustrated based on PVGIS data (Huld et al., 2012). This distribution is also relevant for matching the generation with the own consumption from the analysed buildings and finally for matching the generated surplus with the load profiles of consumers in a REC.

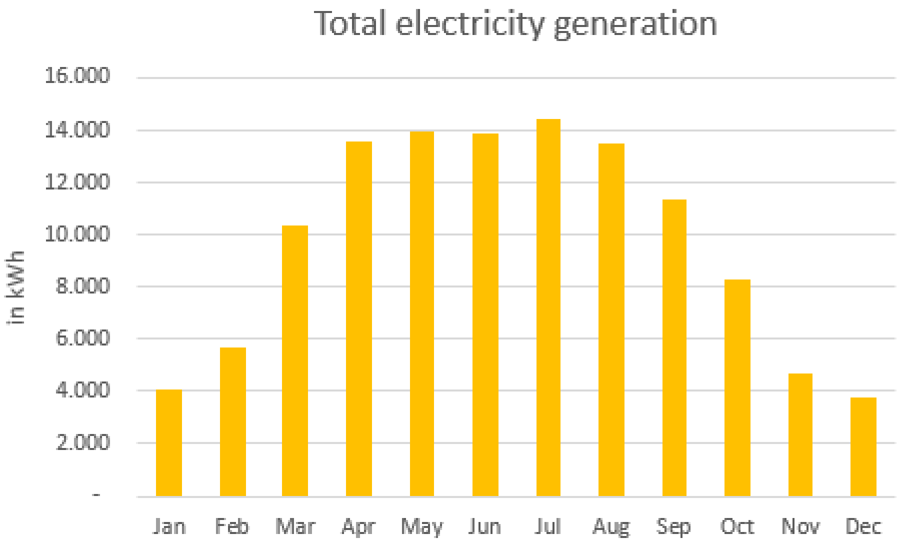


Fig 12: Illustration of a monthly PV generation profile (source: own model)

3.2 Estimating the own electricity consumption

To estimate the own electricity consumption of a building, the usage of a building as well as its size are the key parameter. As most of the analysed buildings underlying this estimation model are neither heated directly by electricity or by heat pumps, the heating of the building is not taken into account for estimating the electricity demand in this model.

3.2.1 Average demand per Building category

To derive an annual total electricity demand in kWh, the annual electricity demand per square meter for each building category has to be estimated. This is done based on data provided by the energy bookkeeping of communities. For reasons of data reliability, only municipalities that are role models related to energy bookkeepings (Energiebuchhaltungs-Vorbildgemeinden) were chosen.

Those role model communities are characterized by collecting energy consumption and generation data for all community-owned buildings at least on an annual basis. For all important buildings, even a monthly collection is required. The collected data have to be put into an energy bookkeeping database and can then be reported.

In Lower Austria more than 220 communities are currently compliant with those energy bookkeeping standards. Those communities are indicated either in light green or dark green in the figure below.

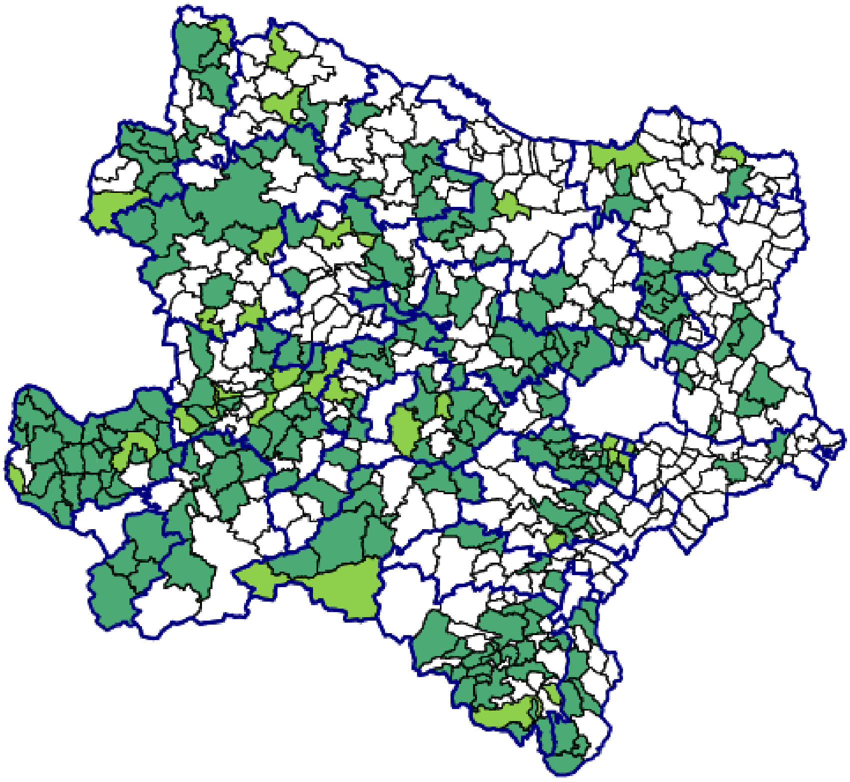


Fig 13: Municipalities that are role models related to energy bookkeepings in Lower Austria (Amt der NÖ Landesregierung, Umwelt- und Energiewirtschaft, 2021)

The bureau of environmental and energy affairs at the state government of Lower Austria (Amt der NÖ Landesregierung, Umwelt- und Energiewirtschaft) kindly provided a comprehensive set of data of all role model communities. These data are illustrated in the below table.

Tab 17: Average annual electricity demand per building category in kWh_{el}/qm (Amt der NÖ Landesregierung, Umwelt- und Energiewirtschaft, 2021)

Building Category	**Number of Buildings**	**Electricity Consumption Arithmetic Mean**	**Electricity Consumption Median**
Town Hall	193	26,7	20,9
Construction Yard	124	45,3	23,3
Kindergarten Building	316	17,9	15,6
Primary School	179	13,8	11,1
Secondary School	52	14,1	11,8
Event Centre	95	26,0	15,7
Fire Station	285	31,1	19,3

As the compiled data show a wide dispersion with discordant values in both directions, not the arithmetic mean is used in the model, but the median.

As the average electricity demand calculated in such a way contains buildings with no electricity-based heating, for better usability of the model a possibility to override the electricity demand of a specific building is offered. This override column is useful in cases when the annual electricity demand of a building is well known already and deviates significantly from the average of the building category.

3.2.2 Calculation of total electricity demand

The electricity demand per building is calculated using the above introduced median consumption data from the energy bookkeepings. For each building the specific electricity demand of the corresponding building category is multiplied with the respective floor area of the building.

In case of overridden electricity demand values, the average numbers from the bookkeepings are substituted by the more accurate estimates.

$$ED\ (n) = A_F * ED_{category} \qquad \text{(Equ. 6)}$$

$ED\ (n)$ = Estimated annual electricity demand per building n [kWh]

A_F= Floor Area [qm]

$ED_{category}$ = Estimated annual electricity demand per qm for a specific building category [kWh]

In order to receive the total electricity demand for all the analysed buildings within the model, the demand estimates are added up.

$$Total\ ED = \sum_{n=1}^{N} ED\ (n) \qquad \text{(Equ. 7)}$$

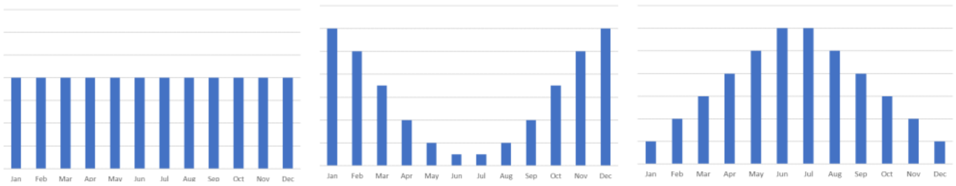
$Total\ ED$ = Total estimated annual electricity demand [kWh]
$ED\ (n)$ = Estimated annual electricity demand per building [kWh]
n = building count
N = total number of buildings

3.2.3 Accounting for seasonal patterns

The meaningfulness of an estimate on a yearly basis is rather limited as PV-based electricity generation and also electricity consumption are tied to seasonal patterns. In order to account for different seasons and associated seasonal pattern, a monthly breakdown gives a more detailed view.

The electricity consumption profile of a building varies dependent on its usage. Schools typically have low electricity consumption during summer due to summer holidays. A town hall typically has a relatively constant electricity consumption over the whole year.

To account for these different usage patterns in the model, one out of three different electricity consumption profiles can be chosen.



constant winter peak summer peak

Fig 14: Different electricity consumption types (source: own model)

These three different usage patterns are based on a percentage distribution for the different months.

Tab 18: Example of own demand estimation (source: own model)

Building category	Name	annual electricity generation [kWh]	Total floor area [qm]	Est. Avg. electr. demand [kWh/qm]	Override of electr. Demand [kWh/qm]	Total electr. demand [kWh]	Electricity consumption profile	**Electricity generation surplus [kWh]**
1 Town Hall	Gemeindeamt	21.224	360	20,9		7.528	constant	**13.697**
2 Kindergarten Building	KiGA Nord	9.433	300	15,6		4.686	constant	**4.747**
3 Construction Yard	Bauhof	11.705	200	23,3		4.660	summer peak	**7.045**
4 Primary School	Volksschule	43.697	450	11,1		4.977	winter peak	**38.720**
5 Event Centre	Veranstaltungszentrum	39.015	450	15,7		7.052	winter peak	**31.964**

In the graph below the distribution of the electricity own demand on a monthly basis is illustrated.

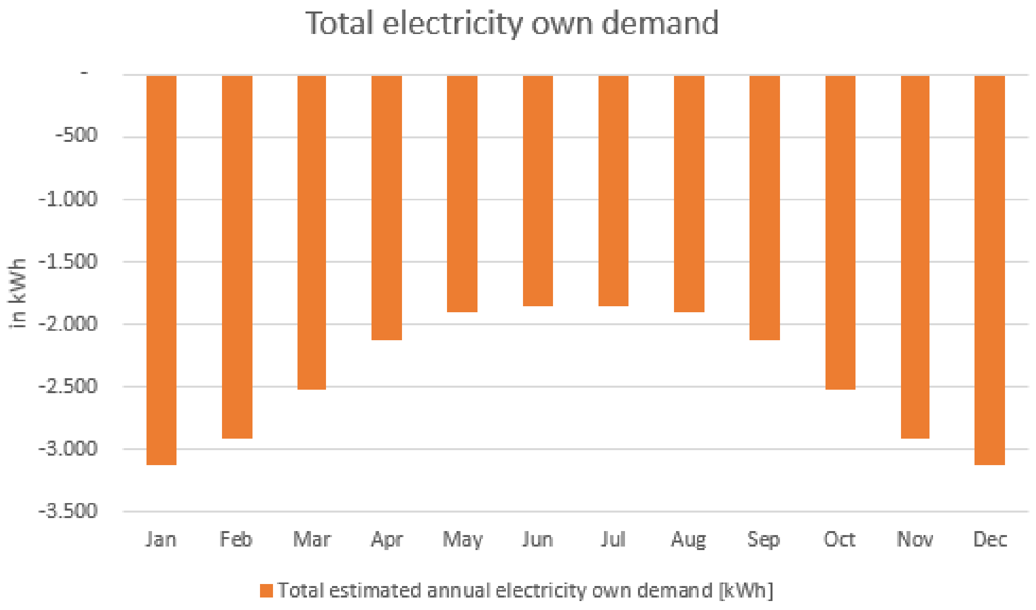


Fig 15: Illustration of a monthly electricity demand (source: own model)

In this example the electricity demand is peaking in winter months and reaches its lowest point during summer. This exemplary pattern is dependent on the selected consumption types. Nonetheless, this pattern is realistic as in winter months more electricity will be needed for lighting and additional heating. In summer months however, this could be partly offset by air conditioning.

3.3 Total electricity surplus

3.3.1 Calculation of total electricity surplus

The electricity generation surplus of a building is calculated as the margin between total electricity generation and total electricity demand.

$$Total\ ES\ (n) = Total\ EG_{PV}\ (n) - Total\ ED\ (n) \qquad \text{(Equ. 8)}$$

$Total\ ES\ (n)$ = Total estimated annual electricity surplus per building [kWh]

$Total\ E_{PV}\ (n)$ = Total estimated annual electricity generation per building [kWh]

$Total\ ED\ (n)$ = Total estimated annual electricity demand per building [kWh]

In order to receive the total estimated annual surplus electricity for all the community owned buildings in the model, all the individual buildings' surpluses or deficits are added up.

$$Total\ ES = \sum_{n=1}^{N} Total\ ES\ (n) \qquad \text{(Equ. 9)}$$

$Total\ ES$ = Total estimated annual electricity surplus [kWh]
$Total\ ES\ (n)$ = Total estimated annual electricity surplus per building [kWh]

The total electricity surplus derived from the formula above represents the main result the model was built for. It gives the local authorities an estimate of the dimension of what amount of electricity can be supplied into a REC and thus what amount can be consumed by other participants of a REC.

This result can also be interpreted as the active contribution of a municipality to reaching the renewable energy targets and climate targets for the state of Lower Austria.

3.3.2 Accounting for seasonal patterns

The calculation presented in the previous chapter gives a rough estimate on a community's potential to establish an energy community. Again, the meaningfulness of annual data is limited as the amount of surplus electricity varies considerably over the year, therefore also the surplus or deficit needs to be broken down to a monthly level.

In order to derive the monthly energy generation surplus or deficit for an individual building, for every month the electricity generation based on the PV generation profile is matched with the same month's electricity consumption based on the chosen consumption profile. To receive a complete picture for all the community's buildings together, the surplus or deficit of each month is summed up.

An example of the described monthly breakdown is illustrated below.

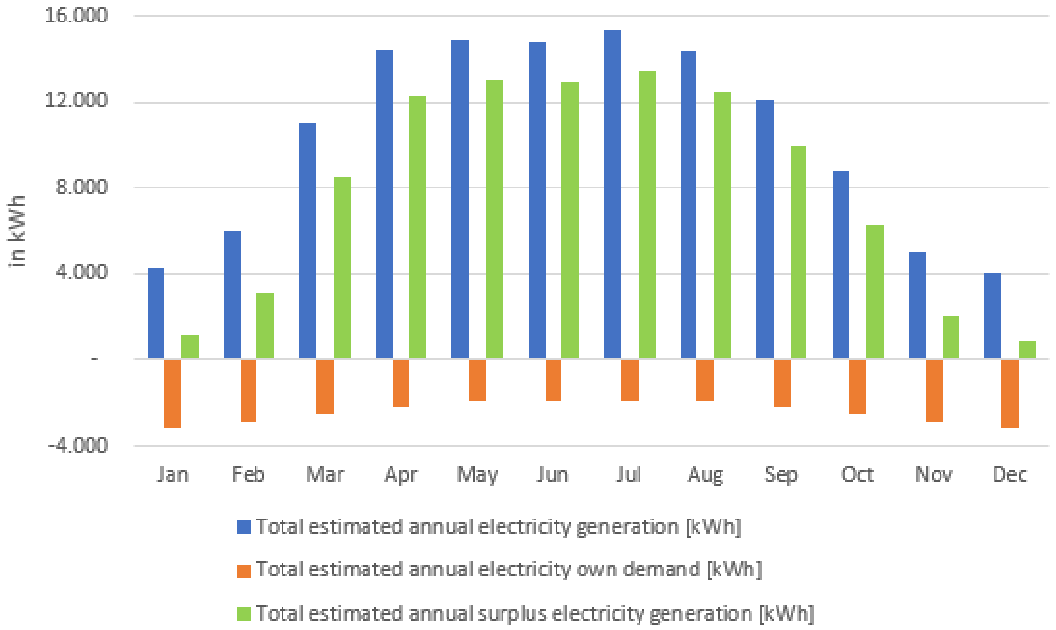


Fig 16: Monthly breakdown of electricity generation, demand and surplus (source: own model)

The monthly analysis is particularly important as the electricity generation from PV peaks during summer, whereas in winter months the generation is considerably low. This was illustrated already above. For means of better clarity, the total electricity surplus only is highlighted below.

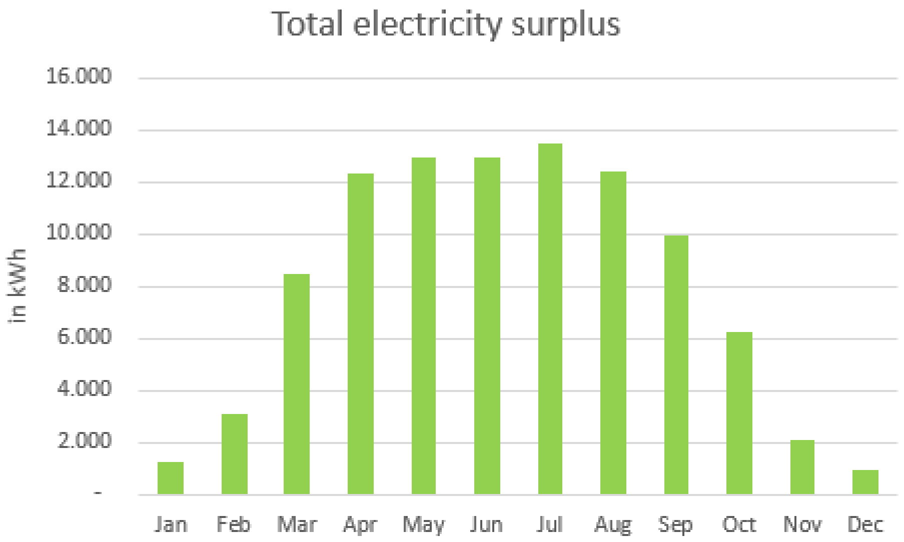


Fig 17: Monthly breakdown of electricity surplus or deficit (source: own model)

Also, the demand patterns can vary over the year, which was already illustrated above. As both parameters, electricity generation and electricity self demand, are estimates also the total electricity surplus and its monthly breakdown must be considered an estimate.

3.4 Use of electricity surplus

As pointed out in the previous chapter, the total electricity surplus from PV can be regarded as contribution to reaching the renewable energy targets of Lower Austria. As an additional step, the use of the electricity surplus is analysed in detail.

The usage of the electricity surplus is dependent on the total consumption and on the seasonal consumption patterns of parties involved in an energy community. In the following, common parties in an energy community are described with particular focus on load profiles.

3.4.1 Households

Hartner et al. (2017) analysed in a case study the load profiles of 821 households located in Upper Austria around Linz over one year using a 15 minute time resolution. This region has a latitude of ca. 48° North and thus is comparable to the region of Lower Austria, which the model described in this work refers to.

The total annual electricity consumption is illustrated below. The median shown as red line lies around 3000 kWh/a. The blue box indicates the range between the 25th and 75th percentiles, which range from 2000 to 4500 kWh/a respectively.

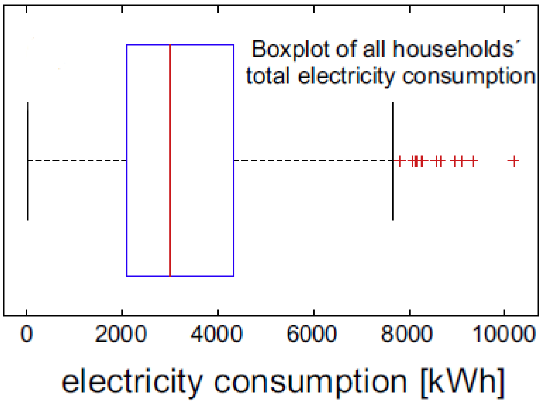


Fig 18: Boxplot of households' total electricity consumption (Hartner et al., 2017)

This illustration gives a rough estimate on total consumption per annum but does not take into account seasonal consumption patterns or even intraday consumption patterns.

Marszal-Pomianowska et al. (2016) illustrate such a seasonal pattern in their work on a high-resolution load model.

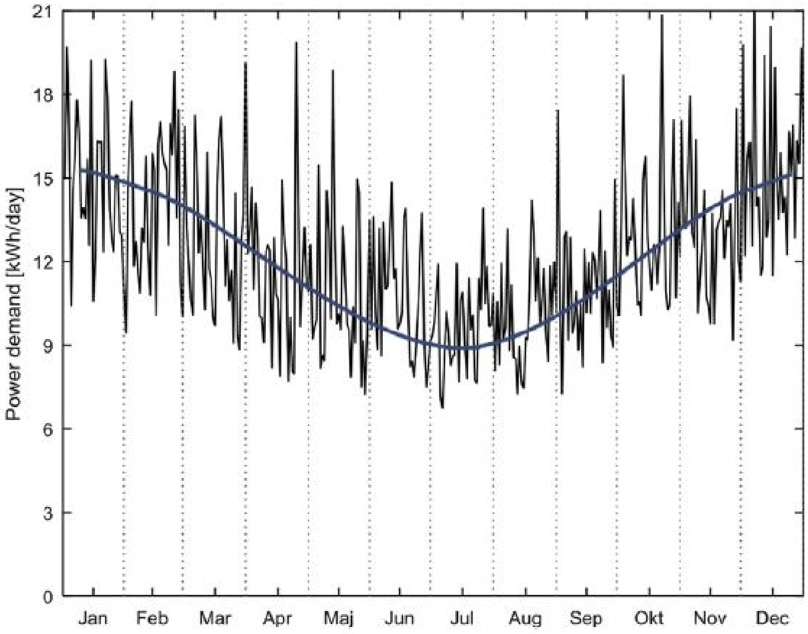


Fig 19: Seasonal pattern of household load profiles (Marszal-Pomianowska et al., 2016)

As electricity generation from PV needs solar irradiation and this occurs only during days, the intraday consumption patterns of households should also be considered.

Hartner et al. (2017) illustrate the intraday load profile of the analysed households from Upper Austria in their work.

Again, boxplots were chosen to illustrate the average hourly load over one year of all households. The red lines indicate the median value, the blue boxes indicate the 25th and 75th percentiles, the black whiskers indicate extreme values, while the read markers indicate households, that are considered outliers.

In addition to the average load profiles, two exemplary households with deviating patterns – one with high load in the morning and one with high load in the afternoon – are illustrated as well.

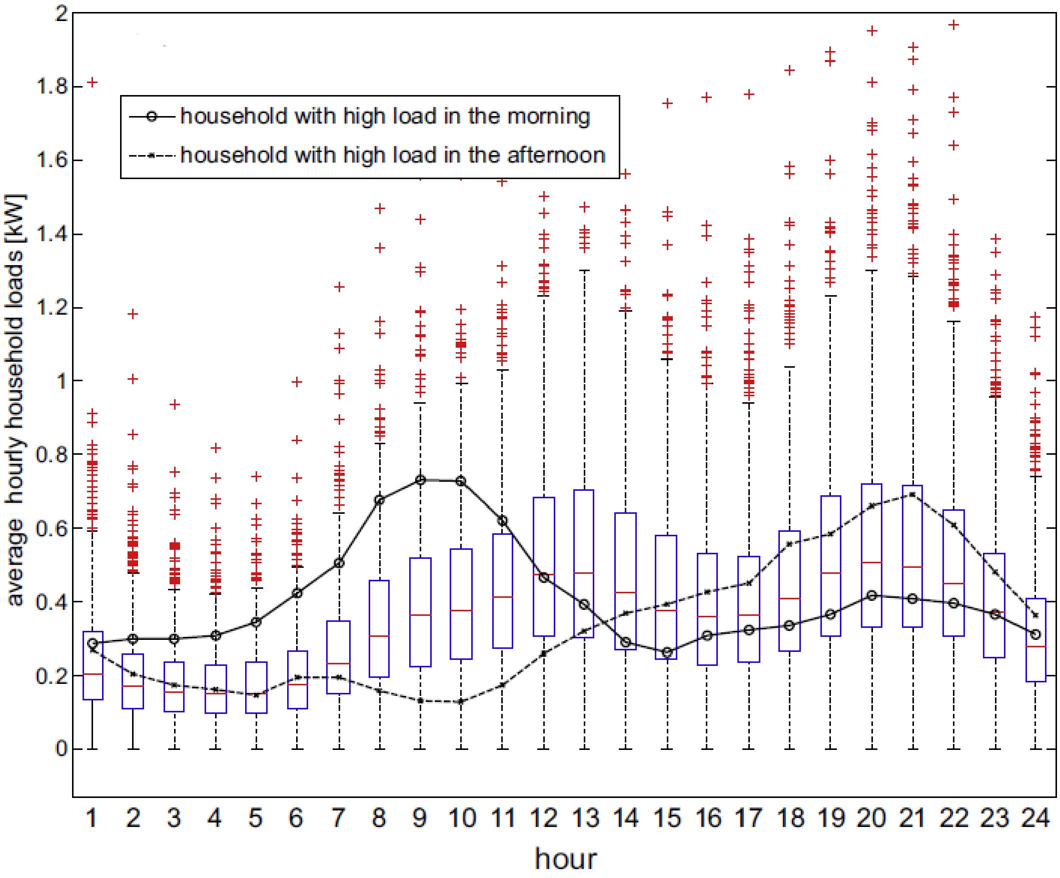


Fig 20: Intraday pattern of household load profiles (Hartner et al., 2017)

In chapter 4.1.3 on the orientation of PV modules on flat roofs an East/West orientation was suggested for better distribution of electricity generation over the day. As is illustrated in the figure above, the suggested East/West orientation should match the elevated load in the morning and late afternoon better than a southbound orientation would.

For estimating the number of households that could participate in an energy community as consumers, the average household consumption needs to be estimated as well. In literature different values can be found.

Hartner et al. (2017) found a median annual consumption of 3000 kWh/a for an area with same latitude as Lower Austria. Azarova et al. (2020) use 3716 kWh/a for a sample of households. This sample is representing a rather rural area in Upper Austria with higher number of single-family houses and larger houses as well. The authors claim in their work that this area might not be representative for whole Austria. However, for the estimations of electricity consumptions of households in Lower Austria, these data might be a suitable estimate.

Deducting from those two consumption numbers described an average annual electricity consumption of 3500 kWh/a per household is suggested in this model.

Of course, the user has to be aware that using average data cannot give exact numbers but is rather an indication. This is particular true if the number is rather small. In such cases, the individual consumption strongly depends on the number of people living in a household and if electricity is used for heating or charging an electric vehicle as well. The larger the number of households analysed, the better those average data will match real consumption patterns.

In this model, two options are available for calculating the maximum number of households that can take part in the REC as pure consumers.

(1) Taking into consideration annual consumption data only, this results in a rather low number of households able to take part in the REC. In our example this results in only 27 households.
(2) The second approach could be to break the annual consumption data down to monthly consumption data. A secondary condition could be to consume all the surplus electricity within the REC and thus to not feed any PV electricity back to the grid. Usually participants in RECs still have a contract with a utility company to receive electricity for periods of not enough generation from the REC.

The underlying load profile for this analysis was derived from Marszal-Pomianowska et al. (2016).

In the figure below, the estimated annual surplus electricity generation is illustrated in green. The monthly consumption for the first option of maximizing the number of households without any seasonal analysis is plotted in light blue. The monthly consumption for the second option of using seasonal patterns is displayed in dark blue.

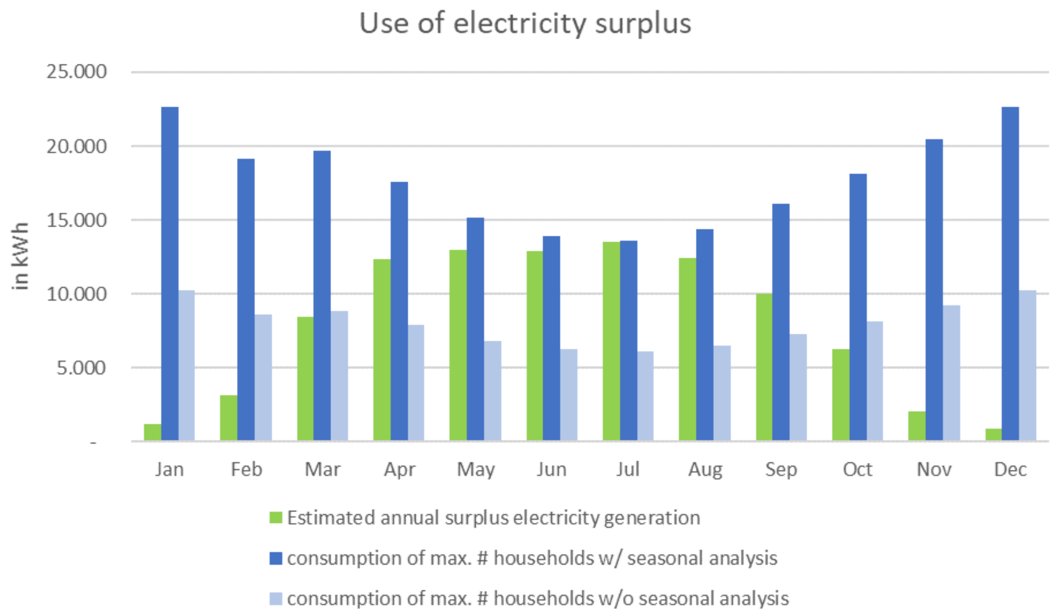


Fig 21: Use of electricity surplus with or without seasonal analysis (source: own model)

The result of those two different consumption patterns can also be expressed as electricity that needs to be consumed from the grid and surplus electricity that is fed into the grid. In the figure below this is illustration is chosen for both options.

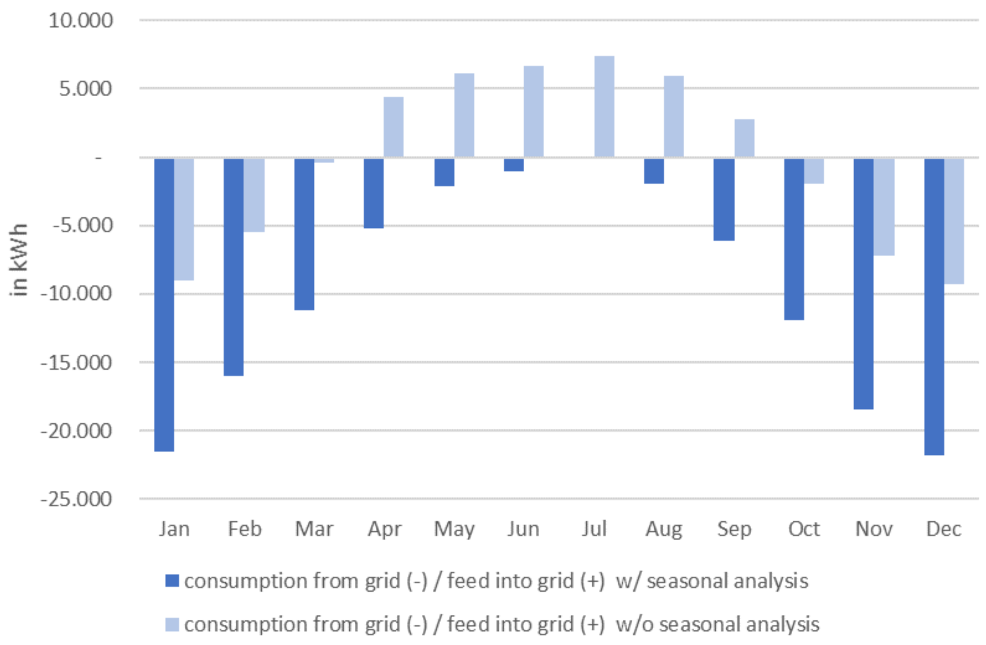


Fig 22: Grid balance with or without seasonal analysis (source: own model)

3.4.2 Other consumers

Households could be types of consumers that take part in RECs in larger numbers as RECs in many cases are driven by private individuals and initiatives. As explored in the previous chapter, household consumption is not a perfect match to electricity generation from PV due to peaks in the morning and evening. More stable consumption patterns could be a valuable complement.

In rural areas agriculture plays still an important role. In many cases farmers use cold warehouses to store the harvest for several months. In such cases a high and stable electricity consumption is the result.

As is indicated below, electricity consumption in agriculture shows a more stable pattern (Andersen et al., 2017). Although the underlying data are from Denmark, the shape of the curves is expected to be very similar for the Austrian case as well.

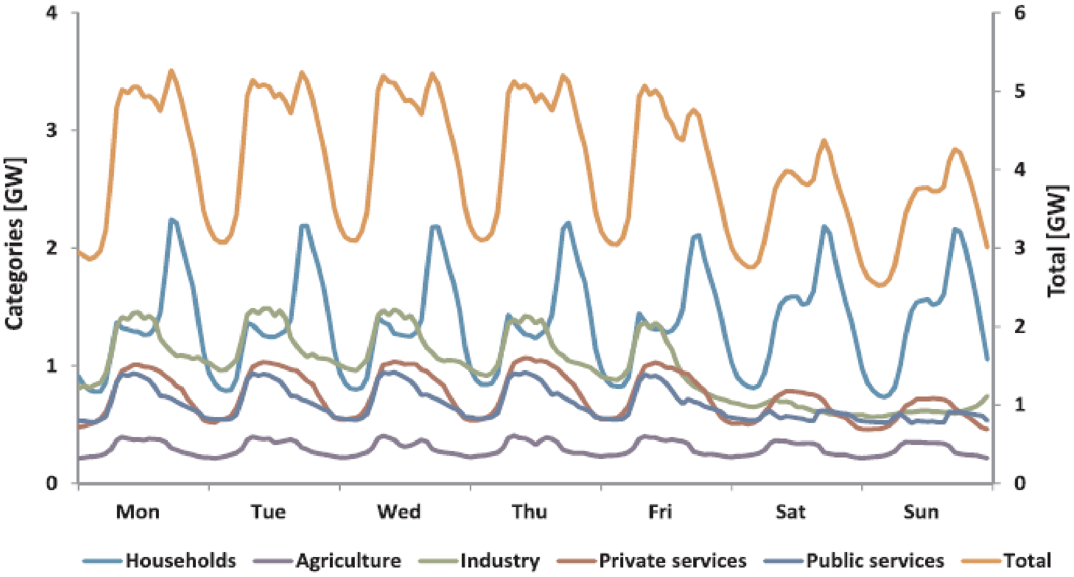


Fig 23: Hourly electricity consumption by customer category (Andersen et al., 2017)

Another consumer category of interest for RECs because of its consumption patterns might be retailers. Particularly in food retailing not only lighting but also cooling of fresh food needs electricity. Below the electricity consumption pattern of UK supermarkets is illustrated during different seasons (Granell et al., 2021).

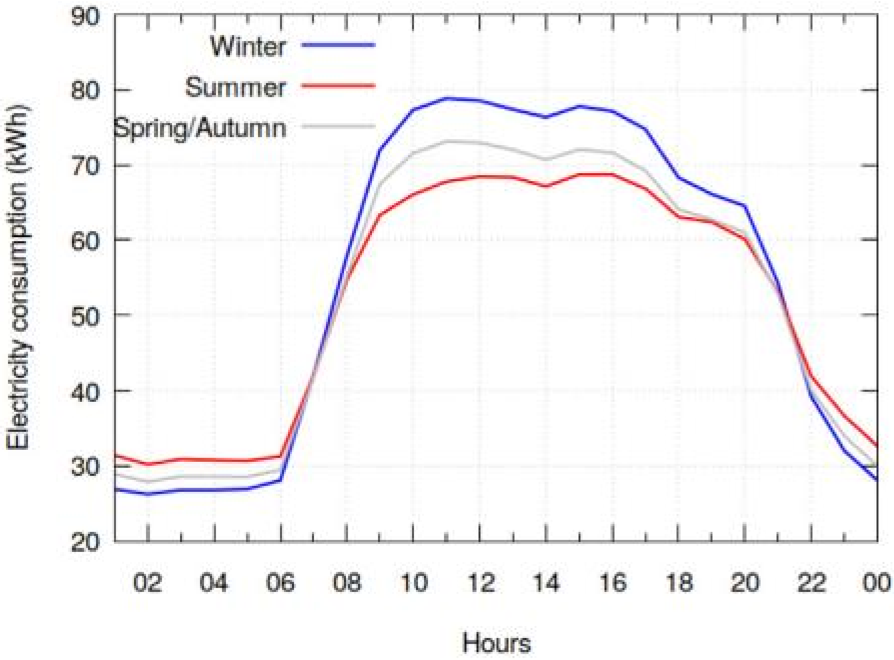


Fig 24: Seasonal electricity profiles of 213 UK supermarkets (Granell et al., 2021)

For RECs according to the Austrian EAG, the participation of large companies is not possible as the law only refers to small or medium enterprises. For means of illustrating the shape of the load curve, the findings from Granell at al. (2021) are suitable, although the absolute consumption values will be only a fraction for small retailers.

The illustrated examples of load profiles from agriculture and retail shops lead to the conclusion that a REC need not solely focus on households but can optimize the consumption within the REC by incorporating other categories of consumers as well.

As the developed model looks on annual and monthly data only, an intraday breakdown is not part of the model. Such an analysis could be part of a further development of the model.

4 Presentation of results

The results of this work are on the one hand a good overview on the details and characteristics of energy communities. Information is provided on the different actors, the general classification, enabling and disabling factors for energy communities. Moreover, an impact analysis illustrates which environmental, technical and social impacts a energy community can deliver.

In particular, the case for Austria and the legal framework there are analyzed in detail. Also, the benefits of RECs within the EAG are elaborated on. Example calculations show the benefits of taking part as consumer in an either local energy community or regional energy community.

On the other hand, a model was developed to help municipalities actively contributing to the climate targets and renewable energy targets of EU, Austria, and the state of Lower Austria.

In this model the impact of roof type, orientation of the roof, roof area, tilt angle of the roof or the modules, irradiation, performance ratio and efficiency of the PV cells were analyzed to derive an estimate for the generation potential of a building. The seasonal patterns of electricity generation based on PV was also examined in detail.

In order to estimate the own electricity consumption, the average demand per building category was used as a benchmark metric. Here, the concept of energy bookkeeping for municipalities, which has been in place already for years in Lower Austria, was helpful to find benchmarking data. For reasons of reliability, only the data of municipalities that are role models related to energy bookkeepings were selected. Also, in this part of the model seasonal patterns were considered as the overall annual number might lead to misleading results.

After calculating the electricity surplus, the usage of the surplus energy is discussed. Again, this is analysed not an annual level but on a more detailed monthly level to account for seasonal patterns.

Although most households do not show the ideal consumption pattern for taking part in an energy community with PV – high consumption in the morning and evening, when PV electricity generation is not at its peak – they should play an important part in this concept. Being part of an energy community and thus engage with the sources of energy production will raise awareness for energy efficiency measures as well as it will raise acceptance for decentralized renewable energy production.

Additionally, other consumers and their load profiles are touched upon. Small businesses or retail shops with a stable energy demand over the day could also be a valuable part of an energy community due to its stable load profile.

5 Conclusion and Outlook

The model developed in this work gives a good estimate for municipalities on how to use their roof areas. During this work some questions came up that could be worth examining in the future. In addition, the model could be extended into different directions.

The building categories in this work were chosen based on the availability of benchmarking data and on the commonness of those buildings in the state of Lower Austria. It could be interesting to analyse if those building types are representative for other regions as well. Also, the comparability of the derived benchmarking data from the energy bookkeepings with municipalities from other European countries could give valuable insights.

The choice of roof types in the model is limited to the three most common ones. An extension of the model to incorporate more roof types could support municipalities with more complex buildings or roof structures.

In order to be able to estimate the electricity generation potential independent of any specific PV manufacturer an overall cell efficiency was used. The model could also be extended by incorporating different cell types and thus different efficiency levels. Also new technologies like bifacial modules, or upcoming materials like perovskite cells, or an increase of the generation potential by tracking systems could be worth considering in a next step.

In addition, other sources of renewable electricity and their application within a REC could be explored as well. An interesting opportunity could be small wind turbines that could complement the reduced PV electricity generation during winter months.

In this work the technological aspects were analyzed. Commercial aspects were excluded from the analysis. For the final decision of a municipality on which roofs to install PV systems, a commercial analysis also needs to be conducted. An extension of the model to incorporate also the financial perspective could be meaningful, although the financial perspective might be subject to change depending on price fluctuations.

In the introduction on energy communities, the role of RECs to contributing to energy justice is analyzed. So far, RECs do not actively contribute to energy justice with respect to vulnerable and underrepresented groups. From here, steps could be researched on how this could be changed to RECs playing an active role in delivering energy justice.

The developed model takes into account seasonal consumption patterns for municipalities' buildings. Those consumption patterns are aggregated to three different ones – stable over the year, peaking in winter, peaking in summer. Here, detailed research could result in more different consumption patterns.

According to the energy bookkeepings, many community owned buildings, particularly older ones, are heated using fossil fuels. For new buildings – community owned or residential – heating is in many cases done by heat pumps, which run on electricity. Thus, the electricity consumption will increase over time to cover also the heat load of many buildings. The current penetration of heat pumps for community owned buildings and the future development could be interesting topics of further research.

Not only the market penetration of heat pumps could be an interesting extension of the model. Also, the field of mobility faces disruption due to the increase of electric vehicles. Taking electric vehicles into account in further research will be necessary in the future. Charging can either be done at home, or at public charging stations. Both options can be supplied by PV electricity from a REC and thus can be economically advantageous. Electric vehicles could either be privately owned or shared within a community. These different options leave room for further analyses. In addition to that, a wide-spread application and combination of heat pumps, electric vehicles and PV electricity generation in the future will intensify the need for intelligent load management at a residential level.

The developed model focuses on the buildings of a municipality because the starting point of this work was the idea of having a local council starting an energy community for its citizens. In practice, also non-commmunity owned buildings could be incorporated into this model. For example, citizens producing electricity with their own PV could be incorporated. Even the restricition on buildings could be abandoned and ground mounted PV plants taken into account as well.

When looking at the intraday patterns of PV electricity generation and household consumption profiles respectively, the introduction of storage solutions, such as batteries, as an extension to the developed model might be an interesting option as well.

The future household consumption patterns could also be influenced by a new way of working for many employees. Working from home and not commuting to office buildings every day might increase residential energy consumption in the future but could also lead to a more stable energy consumption over the day.

Finally, more research could be done into the load profiles of other consumers within an energy community apart from households. Recommendations could be developed on what kind of consumers or businesses would be a good fit for RECs.

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List of abbreviations

BEG	Bürgerenergiegemeinschaft (Citizen Energy Community)
CEC	Citizen Energy Community
CO2	Carbon dioxide
ct	Cent
DERs	Decentralized Energy Resources
EAG	Erneuerbaren-Ausbau-Gesetz (Renewable Energy Expansion Act)
EC	Energy Community
ED	Electricity Directive
EEG	Erneuerbare-Energie-Gemeinschaft (Renewable Energy Community)
ELABG	Elektrizitätsabgabegesetz (Electricity Fee Act)
ElWOG	Elektrizitätswirtschafts- und -organisationsgesetz (Electricity Industry and Organizations Act)
EU	European Union
FIT	Feed-in tariff
GHG	Greenhouse Gas
GW	Giga Watt
GWG	Gaswirtschaftsgesetz (Gas Industry Act)
ICT	Information and Communications Technology
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilo Watt hour
m	Meter
MW	Mega Watt
NREL	The National Renewable Energy Laboratory
PR	Performance Ratio
PV	Photovoltaic
qm	Square Meter
REC	Renewable Energy Community
RED	Renewable Energy Directive
TWh	Tera Watt hour

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