Detailed analyses of meteorological time series for the sizing of storages in renewable energy systems - uncertainties related to inter-annual and database to database variabilities

Hans Georg Beyer

University of the Faroe Islands, Tórshavn, Faroe Islands

Abstract

The sizing of the generation capacity and the storage devices necessary to guaranty certain levels of autonomy and security of supply in solar energy systems shows a high sensitivity to details in the evolution of the driving meteorological parameters. For increased reliability with quantified uncertainty the use of multi-annual time series and is mandatory. Here a multi decadal set is used to inspect the sensitivity to details of irradiance series and the length of the time series inspected on the sizing of a PV plus storage system for an autonomous power supply system. In addition, the variability of sizing results when using data bases from different sources – satellite derived data and data stemming from reanalysis schemes is analyzed. The data applied refer to the location Faroe Islands.

Keywords: System sizing, stand alone system, solar radiation data, variability

1. Introduction

Identifying configurations for a secure coverage of the load in island grids by means of wind or solar power, leads to the need for the inclusion of storage capacity and/or a remarkable oversizing - with respect to the generation capacity needed to assure equality of annual generation and load) – of the renewable generation park. The selection of reasonable combinations of storage capacity and oversizing is usually done by use of time step simulations based on at minimum annual data sets of the meteorological conditions. The interannual variability of the meteorological conditions causes a sensibility of the system sizing to the specific set of of input data selected. There is a broad body of literature discussing the variation of the long term, annual or monthly irradiance sums and the resulting PV generation capacities. The respective discussion of the sizing of the storage capacity for PV systems to reach a desired security of supply is discussed less frequently.

Here, a multi-decadal series of irradiance data with daily time resolution is used to inspect the sensitivity of the sizing of storage devices in stand-alone PV systems designed for the supply of a summertime-only load, to the peculiarities of such a set. In addition, time parallel decadal sets, stemming from different data bases are used to look for the variability of the respective data base specific sizing outcomes.

2. Short view on status of sizing procedures and meteorological input data applied

Examples for the sizing of generation and storage capacity of respective of systems with various capacities are discussed since several decades. Examples are e.g., given by Lund and Mathiesen 2009, Nitsch 2010, Esteban. Zhang and Utama 2012, Cabrera, Lund and Carta 2018, Katsaprakakis and Voumvoulakis 2018, Trondheim et al. 2018, Lund 2018, Bogdanov and Breyer 2018, Dowling et a. 2020. These procedures require sets of meteorological data which reasonably should have a minimal length of one year, that typically form the bases of a time series simulation scheme to track the systems performance depending on the setting of the capacities. The capacities are subsequently varied to approach the desired system performance-

The length of the time periods analysed varies from 1 to up to 30 years, depending on the availability of sets of meteorological data. The selection of these sets and their basic properties – especially their length has been recognized as a critical issue, see.g. Heide et al 2010, Thevenard, D S. Pelland. 2013, Pfenninger and Staffell

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2016, Pfenninger 2017, Bryce et. 2018, Sengupta et al. 2018, Rinaldini et al. 2021, Kies et al. 2021 and, for the case of projected future data sets, Jerez et.al 2015. In this context there is a broad discussion on the year-to-year variability of the annual irradiance sum and thus the expected annual PV generation. In contrast, the interannual variability of challenges for the storage systems connected to the occurrence of extended periods of low generation due to overcast situations has received less attention.

3. Irradiance data, system modeling and sizing schemes applied here

This issue will be discussed based on a multi decadal set of data of the daily irradiance sum and co-located decadal sets stemming from different data bases. Focus is on the sensitivity of the layout of PV/storage system mentioned, to the length of sub-sets selected from this base.

These examples will be performed using a simple model working with a daily timestep that assumes loss-less operation. The meteorological conditions selected refer to the Faroe Islands, located in the Northern Atlantic at ~62°N, ~7.5°W (see fig. 1).. It’s the intention that the results should also cast a light on the requirements on the quality of predictions of future meteorological conditions to reflect details of the statistics of the data sets.

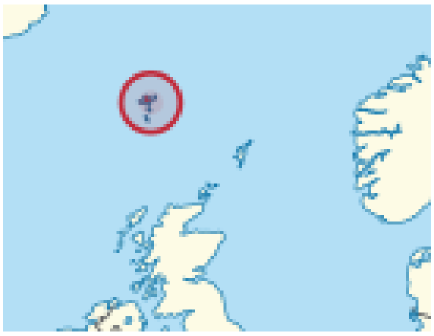

Fig. 1: Map showing thr location of the Faroe Islands, about 400 km north of Scotland.

For the Faroe Islands a 56-year data set with meteorological observations comprising synoptic cloud cover is available. The years 1958-2013 are covered here. Satellite derived irradiance data from the SARAH data base (Müller et al. 2015) are used to calibrate a model giving daily irradiance sums from the cloud cover observations, see Beyer 2020. There a model for the daily PV generation in dependence of the daily irradiance sum based on monitored data of a small PV system on the Faroe Islands, is applied to complete the modelling scheme for the PV generation.

The system analyzed in the next section refer to PV/battery system sized for the safe supply of a fixed load during the summer months May to August. It is assumed, that the load is disconnected for the rest of the year, while the PV stays connected allowing for a fully charged battery at 1st of May. Losses are neglected.

The sizing scheme starts with a setting of the PV generation capacity. The basic sizing is given by the generation capacity to assure equal long-term generation and consumption in the summer months, termed PV-size 1. For the determination of the storage size required for complete load coverage, given a certain generation capacity, a method derived from a scheme given by Haas 94 is used. The storage size required for save supply is estimated by analyzing the evolution of the cumulated balance of generation and load for the period inspected. (see e.g. Beyer 2020, Luther and Gabler 1988). The storage requirements can be assessed by the analysis of the relative maxima and minima of the balance series. They are expressed here by multiples of the daily load consumption [days of load].

4. Results

4.1 Analysis for a multidecadal data set

The scheme is applied first to identify the storage size necessary complete load coverage over the 56-year period, given the PV-size 1. Figure 2 gives for illustration the section of the respective balance process for first two years analyzed.

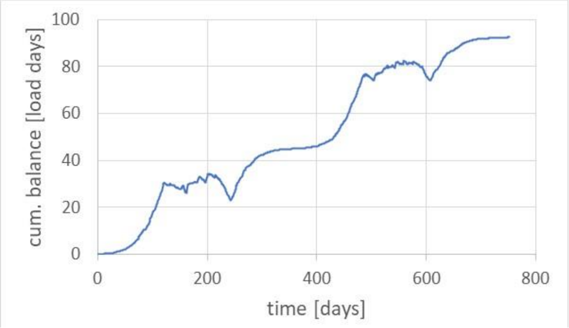

Fig. 2: Section (first 2 years) of the cumulative balance process for a system with PV-size 1 (i.e., equal average generation and load for the period May to August). The periods with active (Mai-August) and inactive load can be recognized. Relative minima occur end of August.

From this section a requirement of ~11.5 days of load can be identified from the max difference of local minima and previous maxima (occurring here for days 204 and 247 resp.). The analysis of the complete set results in a required storage size of ~13.5 days of load. The evolution of the content of a storage of that size is given in figure. 2 for the complete set.

The situation defining that storage requirement appear end of September 1997. For the specific system analyzed here, the appearing local minima in storage content relate to individual years. From this presentation the storage requirement that would result from the analysis of the data for individual years of sections of years can be directly assessed It is visible that challenges for the storage show large variations over the years.

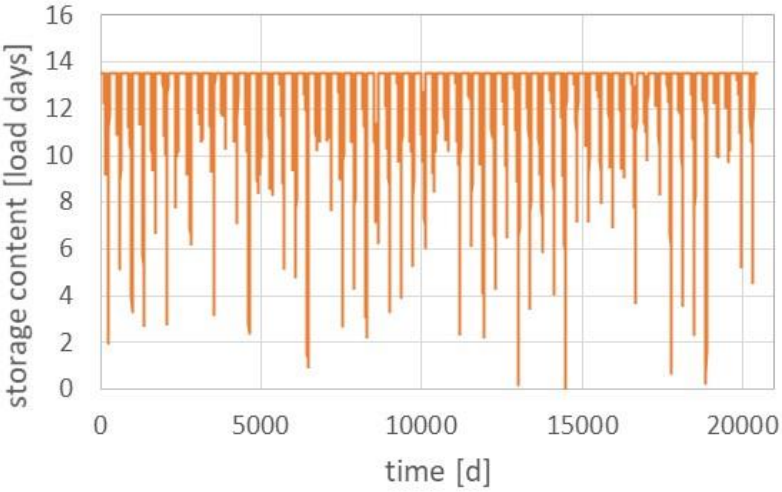

Fig. 3: The evolution of the content of a storage with a capacity of ~13.5 [days of load] for a system with average generation capacity equal to the load in the period May to August over the 56-year period analyzed

Oversizing the generation capacity by a factor of 1.1 results in a reduction of the required storage capacity to ~10 days of load (fig. 3). It can be noticed that the pattern of the challenges changes with the changes in the PV size. The required storage size is now defined by the situation in another year.

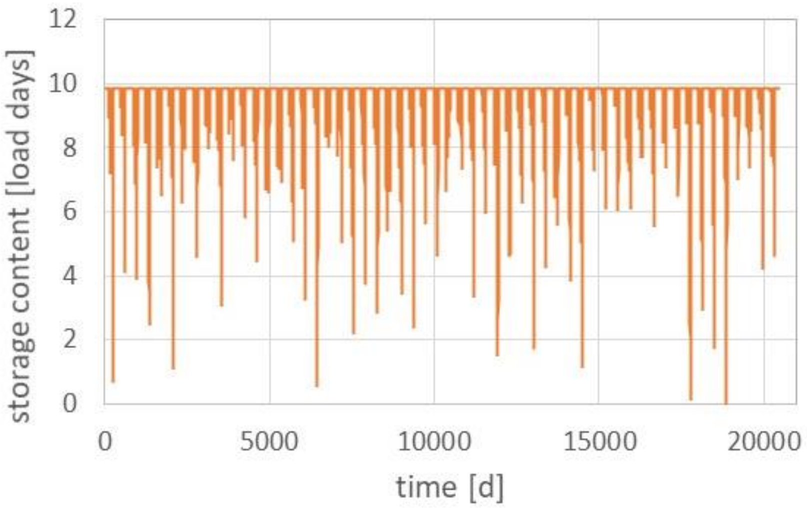

Fig. 4: Same as fig.3 but for a system with PV oversized by a factor of 1.1 and a required storage capacity of 9.8[days of load]

Further increase of the PV-size by sizing factors of 1.2 (fig.5) and 1.5 (fig,6) result in identifying year 1958 as the storage defining one, givin required storage sizes of 7.4 for sizing factor 1.2 and 3.8 for sizing factor 1.5.

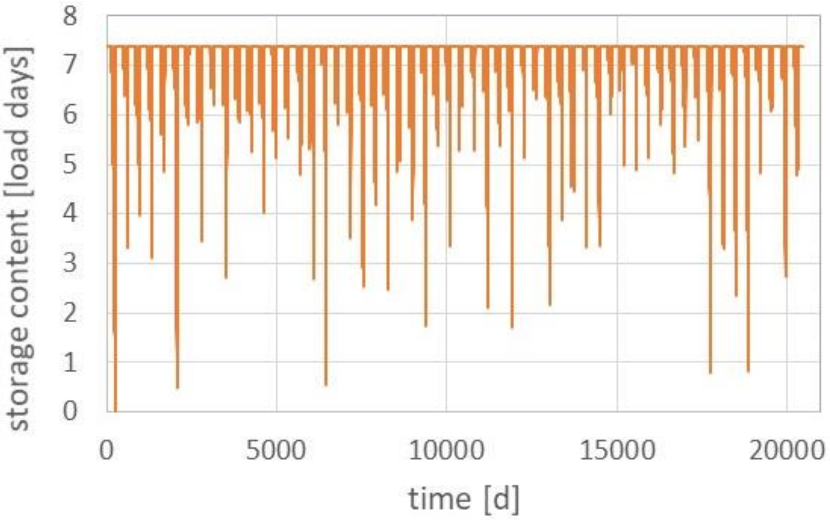

Fig. 5: Same as fig.3 but for a system with PV oversized by a factor of 1.2 and a required storage capacity of 7.4[days of load]

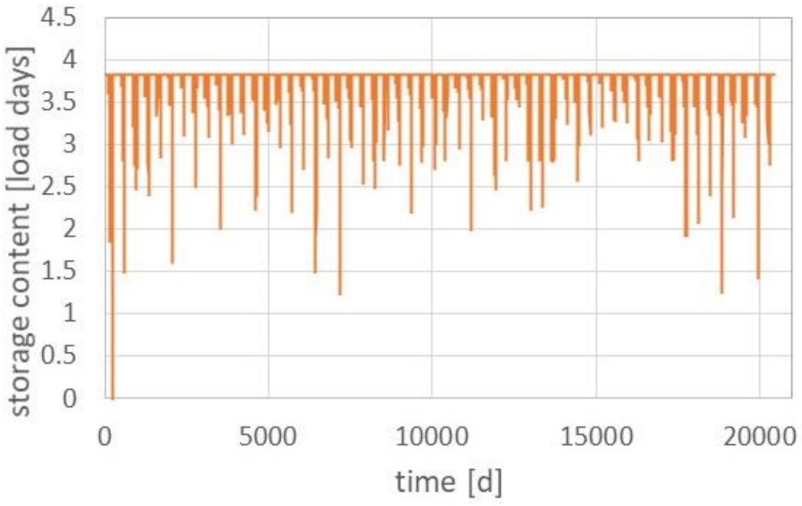

Fig. 6: Same as fig.3 but for a system with PV oversized by a factor of 1.5 and a required storage capacity of 4.8[days of load]

From these results, it is obvious that concepts design “design sets“ fails for systems sensible for the conditions in specific months. These systems show a high sensitivity to the distribution characteristics and sequential properties of the irradiance data, linking the outcome of a sizing based on data for an individual year with a high uncertainty.

Obviously, the final storage sizing can by gained only when inspecting the PV-size specific critical year. From looking at the fig. 3-6 one can – with exception of the case given in fig. 6 – see that there are years giving required storage sizes close to the “final” case. The chances hitting these cases when inspecting not the complete set but only individual sequences of a length of 2, 5 and 10 years is given in figs. 7-9.

The curves are constructed by extracting the information of the required storage size from the storage content data for the case of the sizing actor 1.2 (fig.5), and passing (shifted by days) a sliding window of the respective length over the complete set and sampling the maximum required storage data for that position of the window. Sorting those data by size result in the plots given.

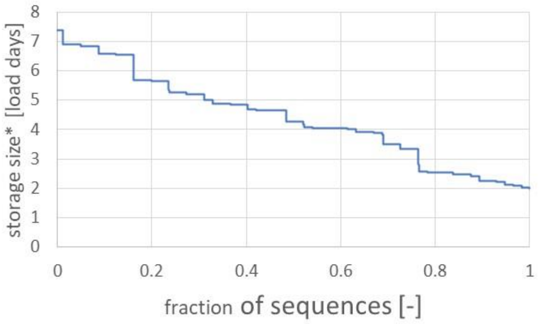

Fig. 7: Distribution characteristics for the detected required storage sizes from the analysis of 2-year sequences. A fraction of 0.2 of all sequences analyzed show a required storage size bigger than ~5.6 days of load (~75% of the ~final value.

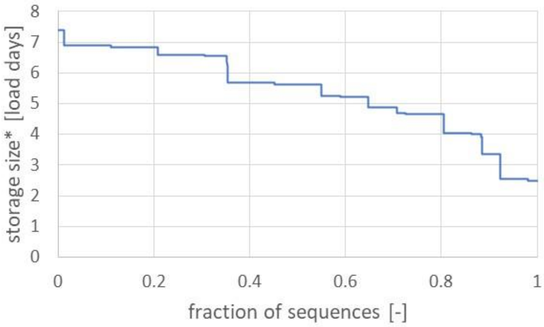

Fig. 8: Same as fig. 7, but for 5-year sequences. A fraction of 0.2 of all sequences show a required storage size bigger than ~6.8 days of load.

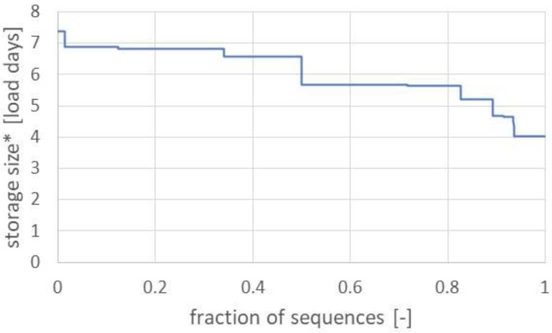

Fig. 9: Same as fig. 1, but for 10-year sequences. A fraction of ~0.3 of all sequences show a required storage size bigger than ~6.8 days of load.

These findings show that, due to the sparseness of occurrence of critical situations, the probability for encountering years standing for enhanced storage requirements is limited, even with longer sets used for inspection. The uncertainty of the sizing for save supply may be assigned with the help of analyses like this, A respective tolerance for handling low probability loss of power events is as well needed.

4.2 Analysis for decadal data sets from diverse data bases

As mentioned, in addition to the uncertainties arising from the intrinsic temporal variability of irradiances, the uncertainties in measured and/or estimated radiance data add to the uncertainties in system sizing.

To inspect the resulting variability, here radiance data sets offered by the PV-GIS server (PVGIS 2021) are used. In detail, data stemming from satellite observations and derived from reanalysis schemes, consisting of the sets:
- PVGIS-SARAH, satellite derived, marked SC
- PVGIS-ERA5, reanalysis product, marked E5
- PVGIS-COSMO-REA6, reanalysis product, marked CO

for the year 2005-2015 are used. Table 1 gives the irradiation conditions for the location Tórshavn,

Tab. 1: irradiation conditions at Tórshavn, Faroe Islands, from databases offered by the PV-GIS server (see text)

	SC	E5	C0
average annual irradiation [kWh/m^2]	692	832	821

The data, given with hourly resolution by the server, are aggregated to sets of daily irradiance sums and processed to PV generation data as described above to be in line with the previous analyses scheme. The calculations of the generation to load balances are done with a consumption equal to PV average generation in the summer month (PV-size 1).

As a result, from the storage sizing for the 11-year data base SC fig.10 gives the evolution of the storage content for a system with PV-size 1. The required storage size was determined to be 13.78 days of load. It is visible tat also from this set the storage requirements from individual years show a high variability.

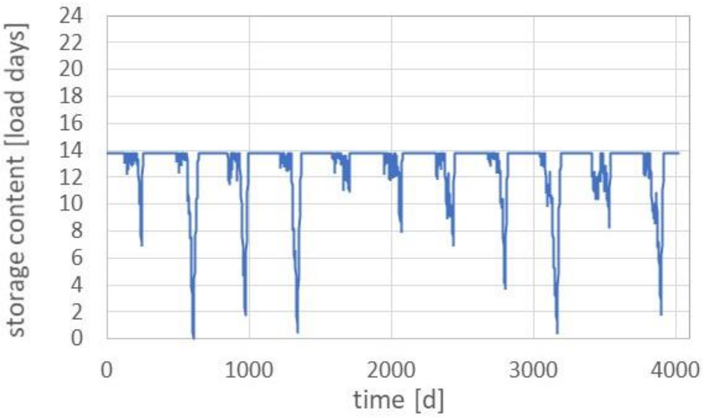

Fig. 10: The 11-year evolution of the content of a storage with a capacity of ~13.78 [days of load] for a system with average generation capacity equal to the load in the period May to August over the 11-year period analyzed. Data base: satellite derived irradiance data set SC. Required storage size identified to be 13.78 [days of load].

The application of the data stemming from the reanalysis information E5 results in a storage requirement of 15.85 days. Comparing the evolution of the storage content in this case (fig. 11) with the previous result, it can be remarked that, while besides the elevated magnitude of the storage content one can observe basically parallel pattern, except for year number for (2008). For that year the storage is remarkable more challenges based on the analyses with the SC set.

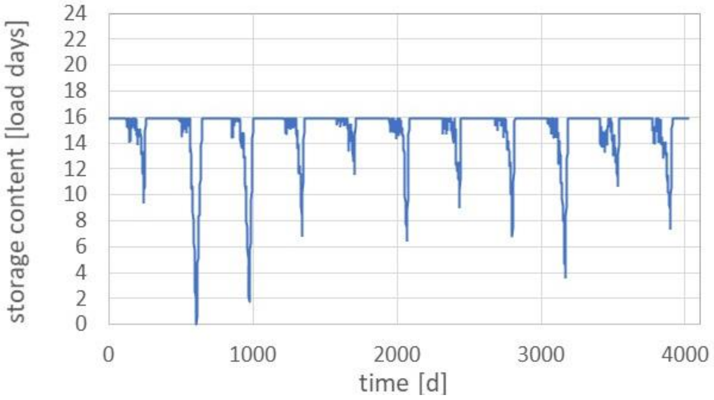

Fig. 11: Same as fig.10 but for a but for the reanalyses set E5. Required storage size identified to be 15.85 [days of load]

Fig. 12 gives the evolution of the storage content stemming from the application of the CO reanalysis set. In this case the required storage capacity is 23.33 days of load. This is remarkably higher than the values identified for the SC, E5 and the cloud cover derived set discussed in the previous section. In addition, the temporal pattern shows, that the storage size is defined by the last year, which does not stand out in the results for the two other sets. These differences are in contrast to the similarity of the annual irradiation given by the CO and E5 sets, casting doubts on the characteristics of the temporal characteristics of the CO sets.

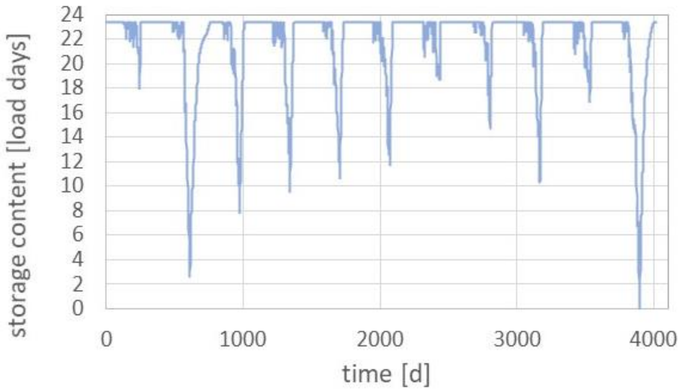

Fig. 12: Same as fig.10 but for a but for the reanalyses set CO. Required storage size identified to be 23.33[days of load]

Fig, 13 gives storage requirements requirements detected for the individual years. The SC and E5 sets show mainly a parallel reaction to a change of year, the CO set present exceptional out-layers in two years

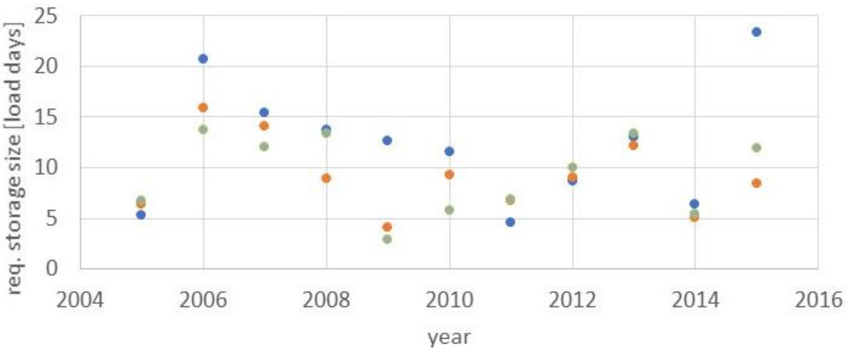

Fig. 13: Storage requirements identified from the data for individual years. The blue dots refer to the CO set, the orange dots to the E5 set and the grey dots to the SC set.

An analysis of the distribution of storage sizes identified on an annual basis is given in fig. 14 by the cumulative fraction of the detected storage requirement presented in fig.13. Excluding the out-layers from the CO set would result in an almost linear relation.

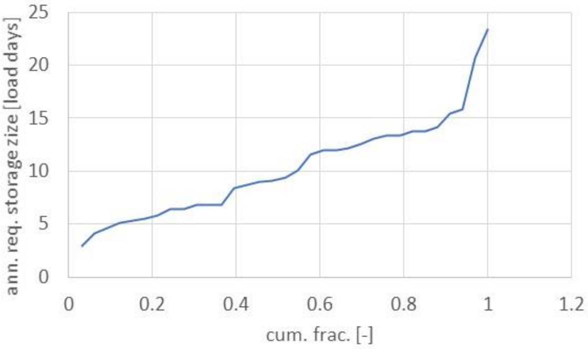

Fig. 14: All required storage sizes detected for individual years using the SC, E5 and CO data sets presented by the storage size as function of the cumulative fraction of the sets (a fraction of about 0.55 the years show required storage sizes smaller than 10 days of load).

Inspecting the storage requirements for oversized PV-generation shows that the relative differences of the results, including the specific results or the CO set, are basically preserved (see table 2). The temporal shifting of the storage defining years is – probably due to the difference in length of the sets less pronounced than for the multidecadal set.

Tab. 1: Required storage sizes identified for different PV oversizing factors applied on data from the PV, E5, and CO sets.

PV sizing factor	PV	E5	CO
1	13.78	1585	23.33
1.1	10.75	12.56	18.20
1.2	7.72	9.34	15.76
1.5	2.84	3.27	8.45

5. Conclusions and Outlook

The examples given should show that the sizing of the storage components of renewable energy systems for autonomy show a high sensitivity to the details of the time series selected for the process. It can be concluded that the reliability of the sizing results (and information on the uncertainty of the expected performance) can be improved by extending the temporal coverage of the meteorological sets applied.

However, this holds only when neglecting changes in the statistical characteristics of the data as induced by climate change. In view of the expected changes in future meteorological conditions, the analysis of the dependency of system performances on details in distribution function and sequential characteristics of the meteorological sets additional requirements on schemes to generate data sets applicable for energy system planning (for context see e.g. Jerez et al. 2015, Jerez et al. 2019).

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