Flexi-Sync

Flexible energy system integration using
concept development, demonstration and replication

REPORT ON REPRESENTATIVE FUTURE WEATHER DATA SETS FOR SELECTED DEMOSITE AREAS

VERSION 1.0

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ABSTRACT

This report is about synthesizing future climate data sets for the demosites investigated in the Flexi-Sync project. Several long-term weather data sets using regional climate models (RCMs) have been used to synthesize representative weather data sets for near-term, mid-term and long-term future climatic conditions. The generated weather data sets will be used in the next stages of the project to assess the climate flexibility and resilience of energy solutions.

ACRONYMS

CDF	Cumulative Distribution Function
ECY	Extreme Cold Year
EWY	Extreme Warm Year
GCM	Global Climate Model
RCM	Regional Climate Model
TDY	Typical Downscaled Year

1 INTRODUCTION

Climate change can induce intensified climate variations and consequently stronger and more frequent extreme events [1]. The frequency of some extreme events have increased over the last 30 years [2] and more weather-related disasters are expected in the future [3]. For example, in Europe increases are expected in heatwaves with shorter return periods, droughts, wildfires, river and coastal floods, and windstorms [4]. Such extreme conditions can affect two-thirds of the European population by 2100 [5]. Climate-induced risks, many due to extreme climate events [6], should be recognized before the further development of energy infrastructures [7]. Extreme weather events are one of the main reasons for energy disturbances [8]. Rather than just aiming for decarbonizing the energy systems and climate change mitigation, it is essential to plan for climate change adaptation as well, especially in urban areas with complex energy flows and interactions.

Understanding the impacts of climate variations on the energy infrastructure is extremely challenging due to the multivariate and multiscale changes of the climate system [9] as well as the complex workflows between climate models and energy systems. Failing to address these challenges can lead to significant performance drops in the energy systems. Furthermore, uncertainties brought by climate change can easily lead to blackouts especially considering high renewable energy penetration levels [10]. Therefore, improving the energy systems to withstand these climate variations in a robust and resilient manner is vital to make the sustainable energy transition a reality. Enhancing the connectivity between climate and energy system models and improving the design of energy systems to withstand future climate variations in a flexible manner will play a vital role in the sustainable transition of energy systems [10].

There has been significant progress in developing climate models and projecting future climate conditions over the last two decades. Moreover, energy models have been developed to consider uncertainties at the design and operation phases. Linking these models to properly understand and quantify the impacts of climate change on the energy system brings unprecedented opportunities to assess and improve the design and performance of energy systems [11]. However, there exist limitations in this regard, especially due to limited knowledge about future climate models in the energy field and consequently lack of suitable approaches to assess to include impacts of climate change in the energy analysis. WP3 in Flexi-Sync is designed to bridge this gap as much as possible.

This report explains the work conducted to synthesize representative weather data sets for future climate considering multiple climate models and uncertainties. The generated weather data sets will be used in assessing impacts of climate change on the energy performance of urban areas in the Flexi-Sync project.

2 FUTURE CLIMATE MODELS AND WEATHER DATA

Global climate models (GCMs) - also known as the general circulation models – are used to simulate future climate conditions. GCMs contain atmospheric model, ocean model, land surface scheme and the sea ice model and simulating climatic conditions under different initial and boundary conditions such as emissions scenarios. GCMs simulate future climatic conditions for the spatial scale of 100-300km^2 [12] which cannot be considered as weather and is coarse for the engineering analysis purposes. Moreover, due to recognized biases, direct use of GCM output in impact assessment is not recommended [13][14]. Therefore, the GCM data should be downscaled by the means of statistical or dynamic downscaling techniques.

One well-known statistical techniques is morphing [15] which combines present-day observed weather data with results from GCMs. Morphing technique reflects only changes in the average weather conditions, neglecting changes in future weather sequences. For example it is not possible to see changes in extreme climatic conditions for the morphed data [16]. Dynamic downscaling of GCMs by means of regional climate models (RCMs) has the advantage of generating physically consistent data sets across different variables [17] [18]. RCMs provide weather data with suitable temporal (down to 15 minutes) and spatial resolutions (down to 2.5km^2), which are suitable for energy simulations.

Outputs of the 4th generation of the Rossby Centre regional climate model, RCA4 [19], is used in this work. RCA4 dynamically downscales five GCMs with the spatial resolution of 12.5km^2: CNRM, MPI, ICHEC, IPSL, and MOHC. More information about the climate scenarios and calculating the climate parameters are available in [20] and [21]. The weather files for energy simulations usually contains Dry Bulb Temperature [^{o}C], Global Radiation [W/m2], Wind Speed [m/s], Wind Direction [degree], Rain Precipitation [mm] [mm/h], Cloud coverage [0-1], Air Pressure [Pa] and Specific Humidity [kg/kg]. Several other parameters can be calculated using the relevant equations and relations, such as Wet Bulb Temperature [C], Relative humidity [0-1], and different components of solar radiation. Achieving the desired climate variables requires extensive coding and analysis which are mainly performed in Matlab and details are described in the previous works of the author (e.g. [20][21]).

It is not possible to rely on short time spans when dealing with future climate scenarios and the recommendation is looking into time spans of 20 to 30 years. Moreover, there are different uncertainties which affect simulated climate data, such as the selected GCM, RCM, emissions scenario and the spatial resolution [22]. In other words, it is not possible to rely on a few number of climate scenarios and a valid assessment should consider multiple scenarios [23][24][25]. This creates the challenge of dealing with large data sets and uncertainties, which has been discussed thoroughly in some previous works (e.g. [22] [21]). Therefore, suitable sets of weather data sets should be synthesized to deal with these challenges.

Synthesizing weather data sets for energy simulations has a long history and several techniques have been developed, which some have been inspiring for creating typical future weather data sets (e.g. [15][26]). Using typical weather year reduces the computational efforts since it enables using one year to perform calculations instead of multiple years. Besides, a consistent form of weather data is ensured so that results from different studies can be compared [27].

Several techniques are available to create typical or reference weather files for energy simulations which Chan et al. [28] have provided a review of some of the important ones. Most of the efforts for creating typical future climate files are based on extending the available approaches on statistically downscaled GCM data, which means those variations and anomalies which induce more extreme conditions in future will be neglected. Nik [20] has developed an approach to create typical and extreme weather data sets to be used in building and energy simulations. The application of the approach has been verified for several type of building and energy studies (e.g. [16][29]) as well as microclimate (e.g. [30]) and energy system analysis (e.g. [10][31]). The Nik's approach [20] has been adopted in this project as described in Section 3.

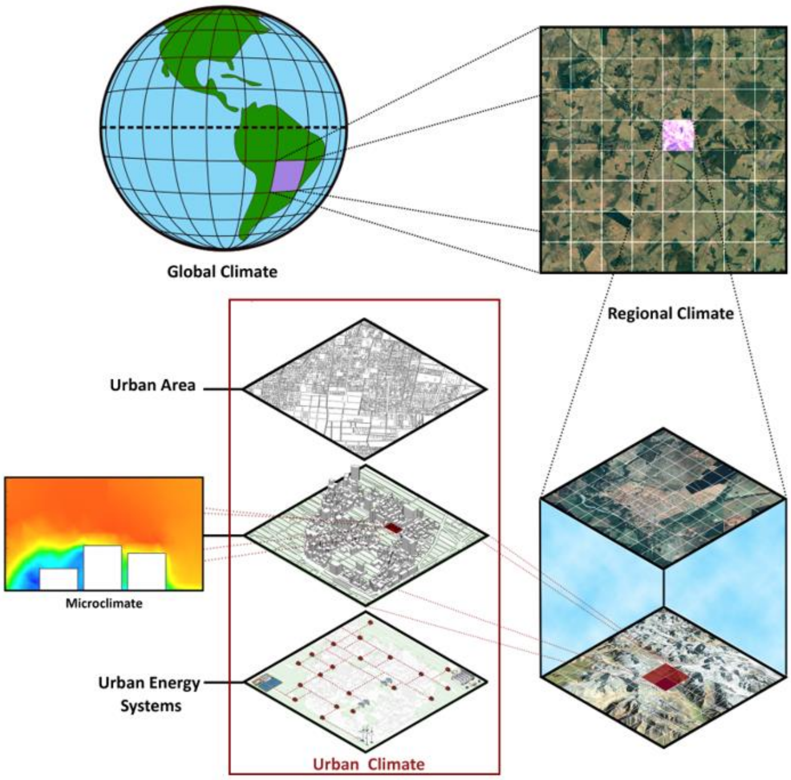

Figure 1. Global climate models (GCMs) simulate future climate conditions at the global scale which will be downscaled dynamically to the regional scale by regional climate models (RCMs). RCM data can be used as weather data in energy simulations, however due to climate uncertainties and the computational challenges with big climate data, representative weather data sets should be synthesized. It is possible to simulate urban/micro-climate as using RCM and/or represenrative weather data. This requires extensive modelling efforts (figure is from [32]).

3 SYNTHESIZING REPRESENTATIVE WEATHER DATA SETS

For each demosite and 30-year time period, three sets of weather data are synthesized according to Nik [20]. In this regard, thirteen sets of RCM data (including five GCMs and three representative concentration pathways or RCPs) are used for each 30-year period. The representative weather files are (1) typical downscaled year (TDY), (2) extreme cold year (ECY), and (3) extreme warm year (EWY).

Assuming a 30-year period (e.g. 2010-2039), TDY is synthesized based on selecting twelve typical months and concatenating them to create a weather file for one year. Selection of TDY (or the typical months) is based on the hourly values of the outdoor air temperature. The hourly temperature of the 30-year RCM data (i.e. 30 [years] × 8760 [hours] ×13 [scenarios]) is being divided into 12 months. For each month, the quantiles of the outdoor temperature are calculated for each single year/scenario and for all the years and scenarios together, which the latter is used as the reference. By comparing the single ones with the reference, the single one with the most similar distribution will be selected as the representative one (the one which its quantiles have the least absolute difference from the quantiles of the reference). This is similar as comparing the cumulative distribution function (CDF) of the single and reference data sets to find the one closest to the long-term distribution. This approach is similar to Finkelstein–Schafer (FS) statistics [33] which is used for TMY [33] weather data sets, however in Nik's approach [20] there is no need to weighing the climate variables since the selection is based only on the dry bulb temperature.

For creating ECY and EWY data sets, the procedure is similar as above, however instead of looking for the least absolute difference, those years with the maximum (for ECY) and minimum (for EWY) difference are selected as the years representing the extreme temperatures for each month. All the required procedures are done in Matlab using the developed algorithms.

The TDY, ECY and EWY data sets together are referred as "representative weather data sets" or "representative climate data" since they together represent the whole range of climate variations, including typical and extreme conditions. This is further investigated in Section 4 which climate data sets for some of the demosites are analysed.

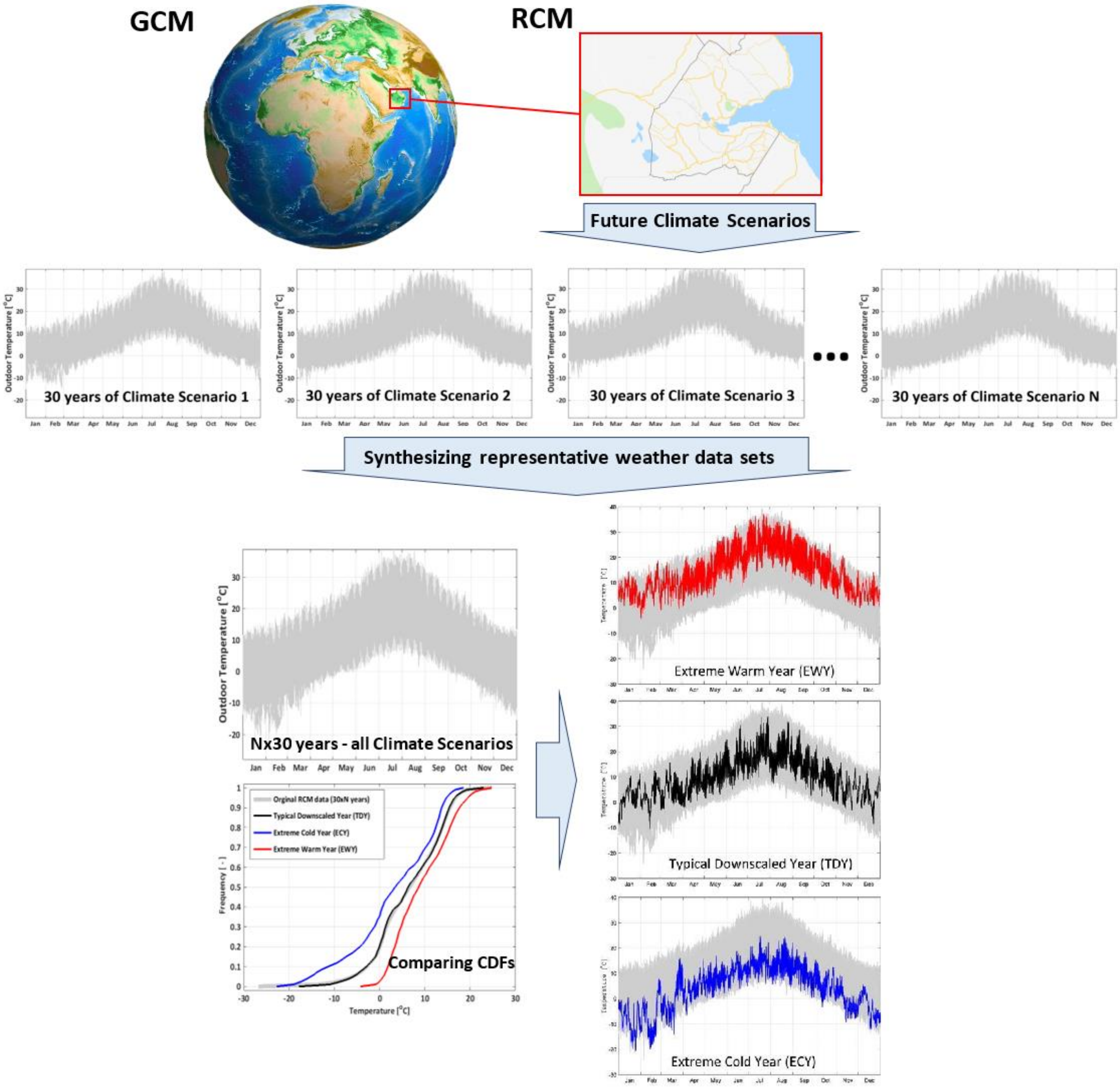

Figure 2. Multiple future climate scenarios are considered and their dynamically downscaled climate data from RCMs are used to synthesize representative future climate data sets to be used in energy simulations, including typical and extreme climate.

4 SYNTHESIZED CLIMATE DATA SETS

Weather data sets for seven cities Berlin, Borås, Eskilstuna, Mallorca, Maria Laach, and Mölndal were synthesized using RCA4 [19] RCM outputs considering five different GCMs and three RCPs of 2.6, 4.5 and 8.5 [34]. Representative weather data sets, including typical and extreme weather, were synthesized for three 30-year periods of 2010-2039 (near-term), 2040-2069 (mid-term) and 2070-2099 (long-term) [20]. In the following, the distribution of the outdoor temperature for the cities are visualized. The “Triple” data set in the boxplots contains TDY, ECY and EWY together.

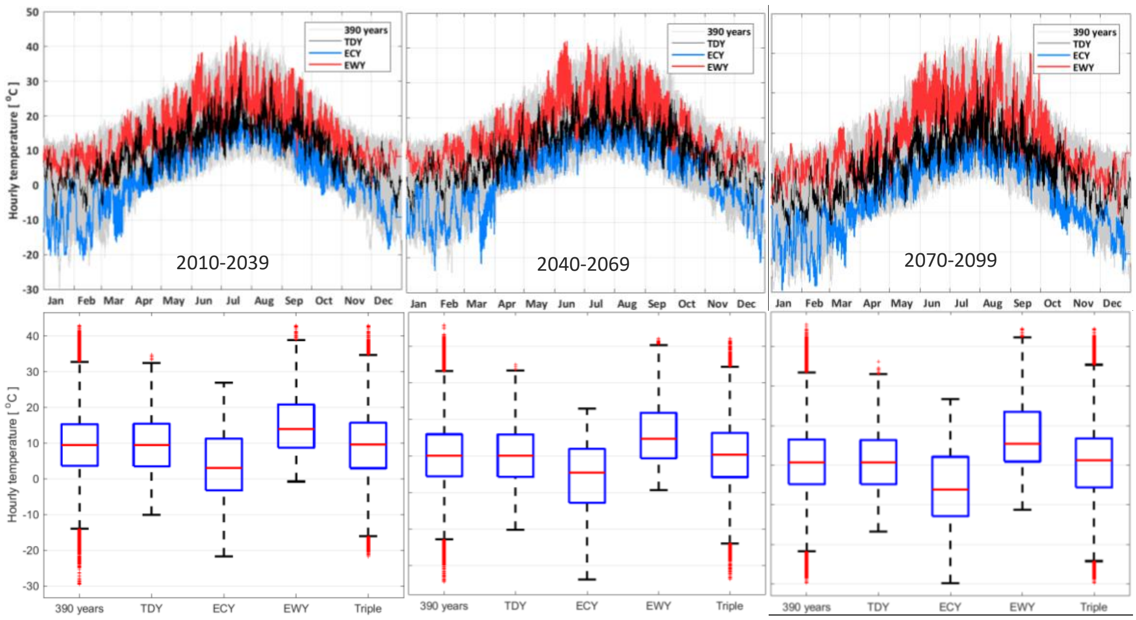

Figure 3. Distribution of the outdoor temperature in Berlin for three time periods considering multiple future climate scenarios.

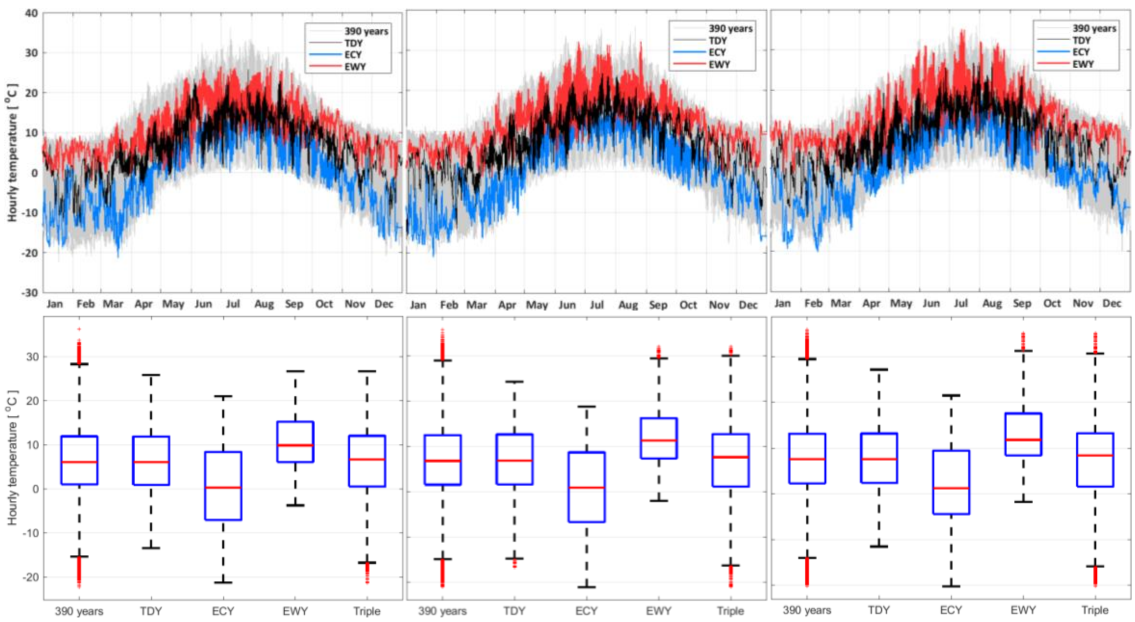

Figure 4. Distribution of the outdoor temperature in Borås for three time periods considering multiple future climate scenarios.

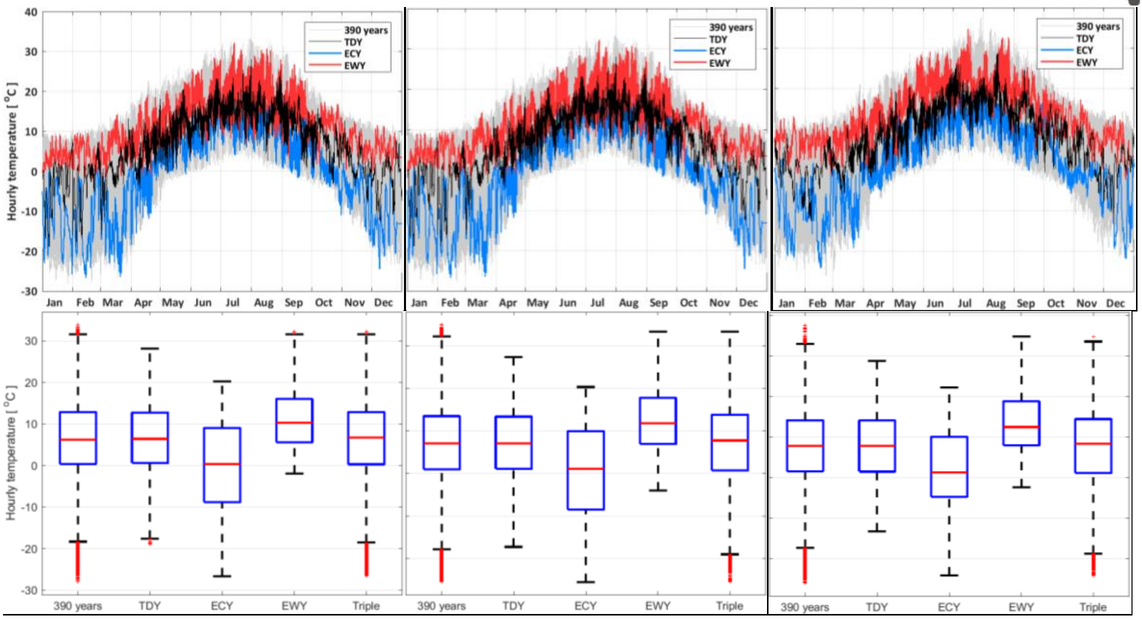

Figure 5. Distribution of the outdoor temperature in Eskilstuna for three time periods considering multiple future climate scenarios.

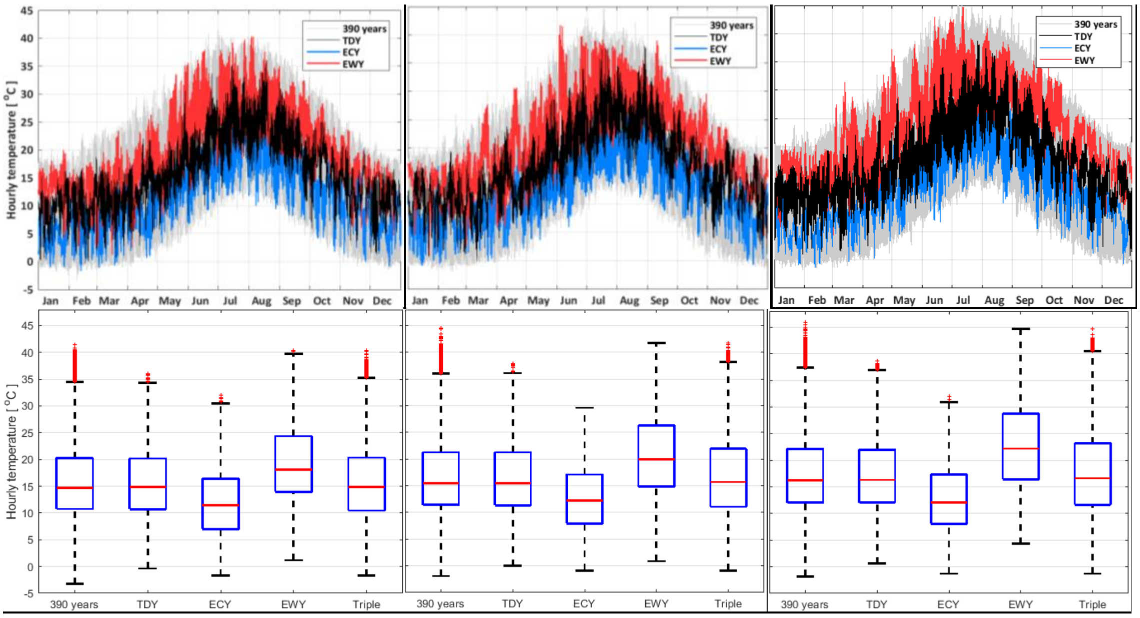

Figure 6. Distribution of the outdoor temperature in Mallorca for three time periods considering multiple future climate scenarios.

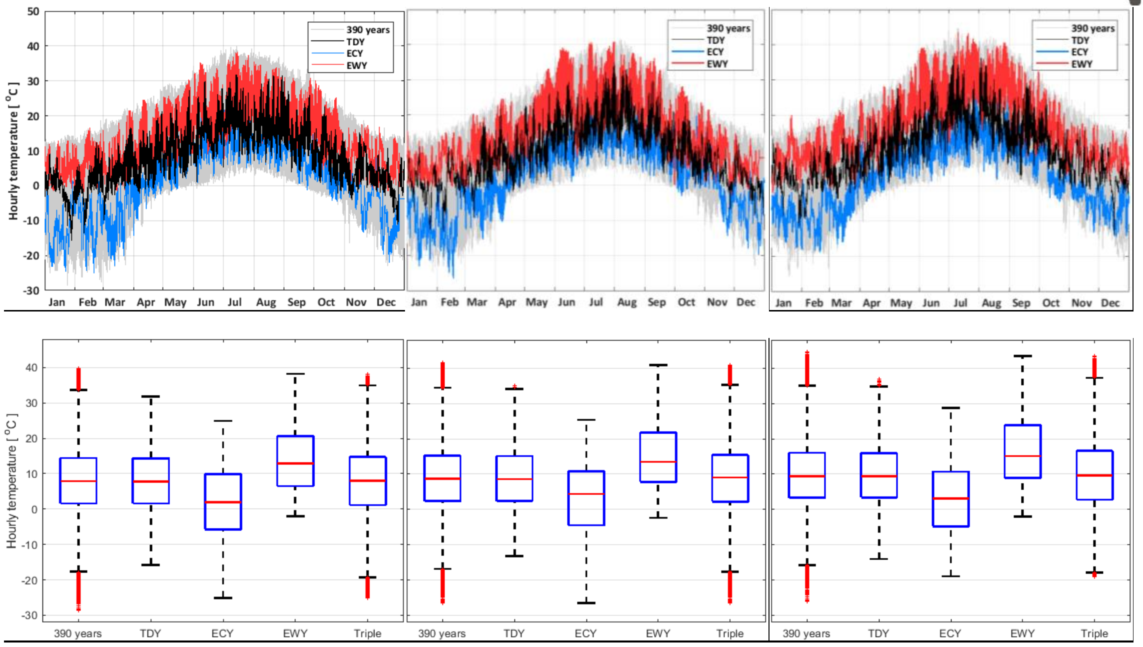

Figure 7. Distribution of the outdoor temperature in Maria Laach for three time periods considering multiple future climate scenarios.

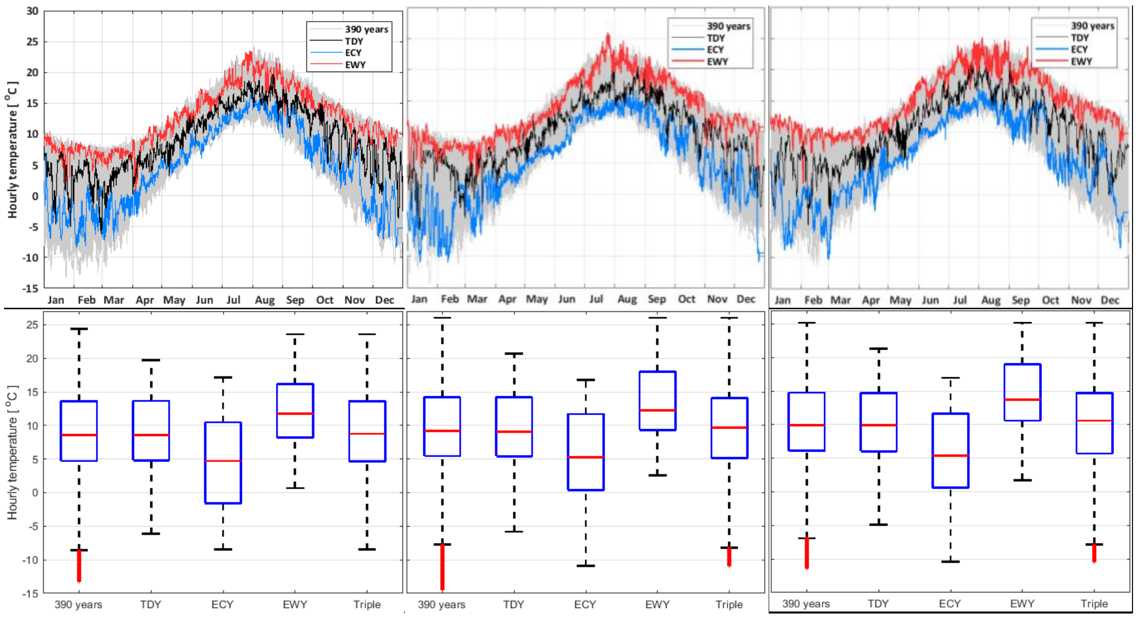

Figure 8. Distribution of the outdoor temperature in Mölndal Laach for three time periods considering multiple future climate scenarios.

As is shown in the figures, the synthesized representative weather data sets can represent the typical and extreme conditions with a high accuracy and in a way that they represent the whole range of variations. This means that we can reduce the number of simulations considerably while a good representation of climate variation at the hourly temporal resolution. Consequently, it is possible to take into account both the long and short-term variations of climate without neglecting extreme weather events.

The relative scale of variations depends on the selected climate variable (e.g. temperature, global radiation, relative humidity etc.) and time scale (decadal, annual, seasonal, monthly etc.). For example, the relative increase in the average temperature is different if we look at the annual or seasonal averages, as is discussed in [10] and [35].

Moreover, the importance of extreme events and seasonal variations can be different depending on assessing energy demand or renewable generation. For example, for assessing the potential of solar and wind energy in an urban energy system, the extreme conditions should be picked based on the hourly values. In some cases, to account for seasonal variations we should pick different percentiles of the hourly values. More details are described in [10].

Percentiles of the outdoor temperature for the considered cities are plotted in Figure 9. In this figure, dots mark the 5th, 25th, 50th, 75th and 95th percentiles which their values are shown in Table 1. As expected, the Scandinavian cities have a colder climate and the warmest city is Mallorca. It is interesting to see that the relative increase among periods compared to the first one (2010-2039) is larger for lower percentiles. For example, for Mallorca the increase of the 5th percentile is around 12% in 2040-2069 and 23% in 2070-2099, both compared to 2010-2039. These values for the 95th percentile are around 4% and 8% respectively. The values for the 5th percentile in Borås are around 25% and 44% while for the 95th percentile are around 3% and 8%. This means that by climate change the decrease in extreme cold conditions is more than increase in extreme warm conditions. However, it does not mean that we can neglect extreme warm conditions, since still they will increase and reach higher values than we have experienced.

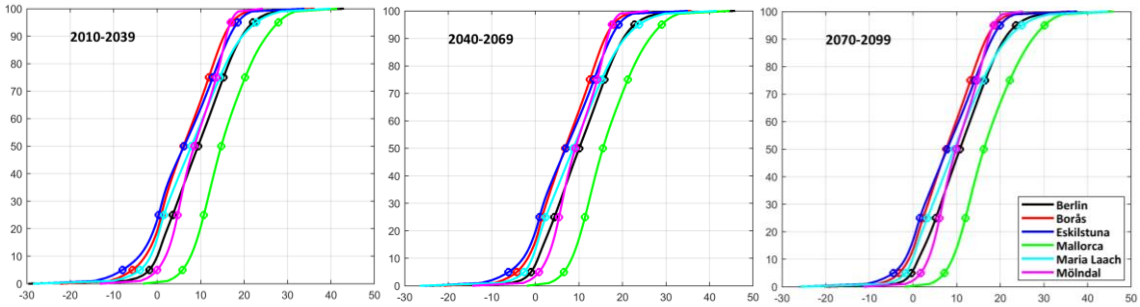

Figure 9. Percentile of the outdoor temperature [ºC] for the considered cities over three time periods.

Table 1. Values of five percentiles of the outdoor tempeature [ºC] in the cities and their increase over time.

		5th	25th	50th	75th	95th
Berlin	2010-2039	-1.80	3.58	9.41	15.26	22.07
	2040-2069	-1.00	4.39	10.06	15.90	22.79
	2070-2099	-0.36	5.25	10.75	16.54	23.62
Borås	2010-2039	-5.66	0.98	6.05	11.90	17.22
	2040-2069	-4.26	1.56	6.82	12.53	17.81
	2070-2099	-3.15	2.31	7.61	13.19	18.65
Eskilstuna	2010-2039	-7.98	0.36	6.19	12.81	18.53
	2040-2069	-6.17	0.97	7.02	13.47	19.11
	2070-2099	-4.49	1.59	7.84	14.17	19.95
Mallorca	2010-2039	5.84	10.77	14.75	20.26	27.88
	2040-2069	6.55	11.41	15.52	21.25	29.00
	2070-2099	7.19	12.03	16.24	22.17	30.13
Maria Laach	2010-2039	-3.93	1.57	7.87	14.42	22.83
	2040-2069	-2.58	2.39	8.70	15.22	23.83
	2070-2099	-1.70	3.31	9.44	16.02	24.98
Mölndal	2010-2039	0.01	4.72	8.54	13.60	16.91
	2040-2069	0.85	5.44	9.19	14.21	17.60
	2070-2099	1.79	6.09	9.88	14.76	18.47

5 CONCLUDING REMARKS

Future weather data sets for seven cities of Berlin, Borås, Eskilstuna, Mallorca, Maria Laach, and Mölndal were synthesized using RCA4 regional climate model, considering five different GCMs and three RCPs. Representative weather data sets (including typical, extreme warm and extreme cold years) for three 30-year periods of 2010-2039, 2040-2069 and 2070-2099 were synthesized, using the novel method developed by the author. This enables us to perform an unbiased impact assessment of climate change on the energy performance of urban areas.

Assessing the impacts of climate change and investigating extreme conditions depend on several factors such as the considered climate scenarios and geographical location. For example, having a certain average temperature over a week in Sweden might be considered as extreme warm condition but not in Spain. However, according to the results, we can conclude that the decrease in extreme cold conditions is more than increase in extreme warm conditions. However, it does not mean that we can neglect extreme warm conditions, since they will increase and reach higher unprecedented values.

The synthesized weather data sets will be used to simulate the energy demand and renewable generation and their variations by climate change and extreme events. Results will be used to analyse energy systems, aiming at investigating the climate flexibility and resilience of the suggested energy solutions.

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