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Stratego
ENHANCED HEATING
& COOLING PLANS

Creating Hourly Profiles to Model both Demand and Supply

Work Package 2

Background Report 2

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STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

Contents

Nomenclature

Variable	Description
ABM	Agent based modelling
CDD	Cooling degree day
EV	Electric vehicle
HDD	Heating degree day
HW_H	Hourly hot water demand
HW_Y	Yearly hot water demand
MW	Megawatt
PJ	Petajoule
PV	Photovoltaic
SH_H	Hourly space heating demand
SH_Y	Yearly space heating demand
TH_H	Hourly total heat demand
TH_Y	Yearly total heat demand
TSO	Transmission System Operator

1 Introduction

To analyse an energy system on an hourly basis, hourly distributions must be obtained for demands and productions that vary from hour to hour. For example, this includes all demands such as electricity, heat, cooling, and transport as well as production from sources such as wind, solar, and wave power. This is a very large task since each year includes 8760 hours (or 8784 for a leap year) so a methodology required to build these hourly distributions needs to be applied and a specific methodology is elaborated in detail in this report.

The focus here is at the national level, rather than for example at the building level. Many studies in the past have developed hourly distributions for electricity, heating, and cooling demands at the building level [1-4], but the novelty of this methodology is to develop these distributions at a national level. These are necessary for national energy strategies that are often carried out to investigate issues such as new technologies, targets, and policies [5-7].

The main distributions for non-dispatchable components in the energy system are presented in Table 1. All of the major branches on the demand side of the energy system are non-dispatchable, since the consumer expects their energy demands to be met at the time required. On the supply side, the non-dispatchable components considered here are wind, solar, and waves. This is not a complete list, since other distributions could be necessary depending on the capabilities of the energy systems analysis tool. However, the aim here is to cover the key sectors that are usually non-dispatchable. The complexity associated with each distribution varied significantly depending on the type and availability of data, but even if the distribution is relatively simple to create, a brief description is included here for completion.

Table 1: Distributions created in this study for non-dispatchable components in the energy system.

Demand	Supply
Electricity	Wind Power
Heating	Solar Electricity (Photovoltaic)
Cooling	Solar Thermal
Transport	Wave Power

After creating the distributions, some are compared against existing data: these are the distributions for heating, wind, and solar (PV and thermal). The results suggest that each technique provides a good approximation of the demand or supply that it presents. To quantify this, the distributions were calculated using the methodology defined here for different countries. Subsequently, they were compared with historical data, to examine if the distributions created here produced similar results to the data measured locally. Overall, the distributions that could be validated demonstrated very similar trends to the historical data, but there are differences in the exact values at each hour. The similarly was quantified using a regression analysis, but the values did not correlate very well with a visual comparison of the distributions, so this should only be seen as a guide. Considering the original purpose, which was to develop hourly distributions for national energy modelling, we concluded that these distributions are sufficiently accurate for creating and evaluation national energy strategies. The electricity demand is based on measured data, so this did not need to be validated, while the remaining distributions, which are transport and wave power, were not validated since no local measurement data was obtained to do so.

2 Methodology and Results

Each distribution has a single value representing each hour of the year, which results in a total of 8760 hours (or 8784 if it is a leap year). Each data point represents a value between 0-100% of the maximum hourly value over the year. For example, Figure 1 illustrates how an hourly distribution of the Irish electricity demand for January 2007 is distributed over the month. By normalising the data in this way, it is possible to use the hourly distribution for different total values. For example, Figure 2 illustrates how the normalised distribution in Figure 1 is used to represent three different total electricity demands over the month of January. This enables various different scenarios to be easily compared using the same distribution in an energy system analysis tool. Similarly, the normalised distribution can be adjusted based on an installed capacity by adjusting the peak hourly value recorded during the year, which can also be required depending on the methodology in the energy system analysis. Finally, by normalising the distributions it is also possible to compare different countries with one another, independent of scale or annual totals. This can expose the different challenges facing countries, depending on the resources and demands that are present. In the following section, the data collected and any proceeding adjustments applied are described for each hourly distribution. Once again, these distributions are designed for national energy system analysis tools, and hence the focus is on national data and behaviour rather than the building level for example. Therefore, after describing the methodology, it has been applied here to different EU member states to demonstrate how the hourly distributions can be applied and to validate the results. The member states considered at different points in the study are Croatia, Czech Republic, Denmark, Germany, Italy, Romania, and the United Kingdom.

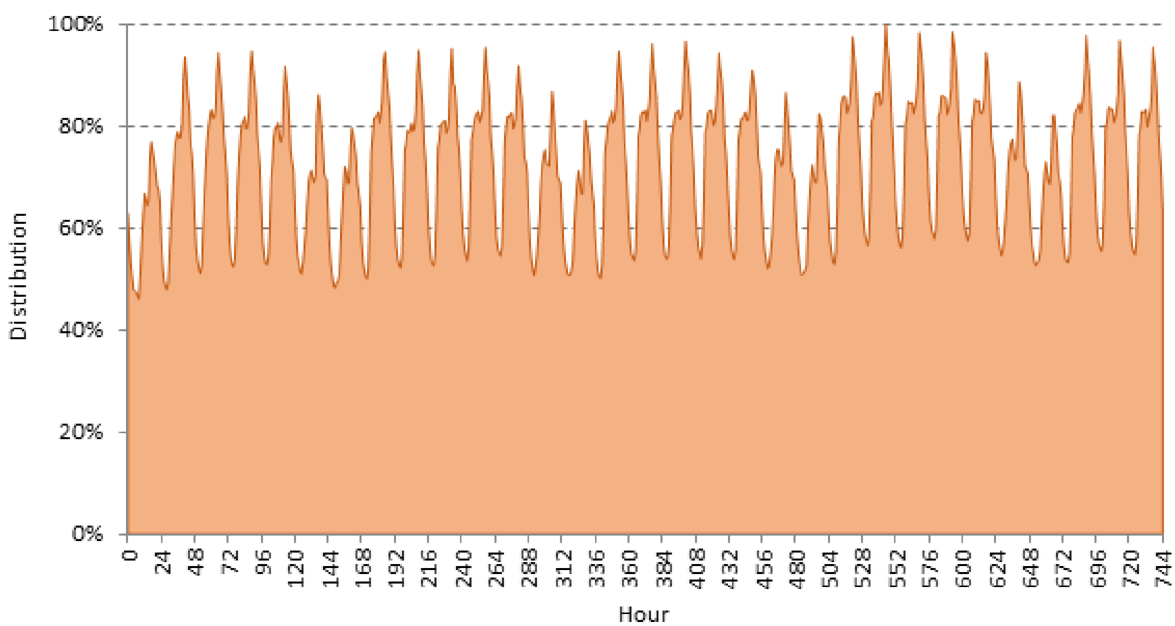


Figure 1: Distribution of Irish electricity demand for January 2007 [8].

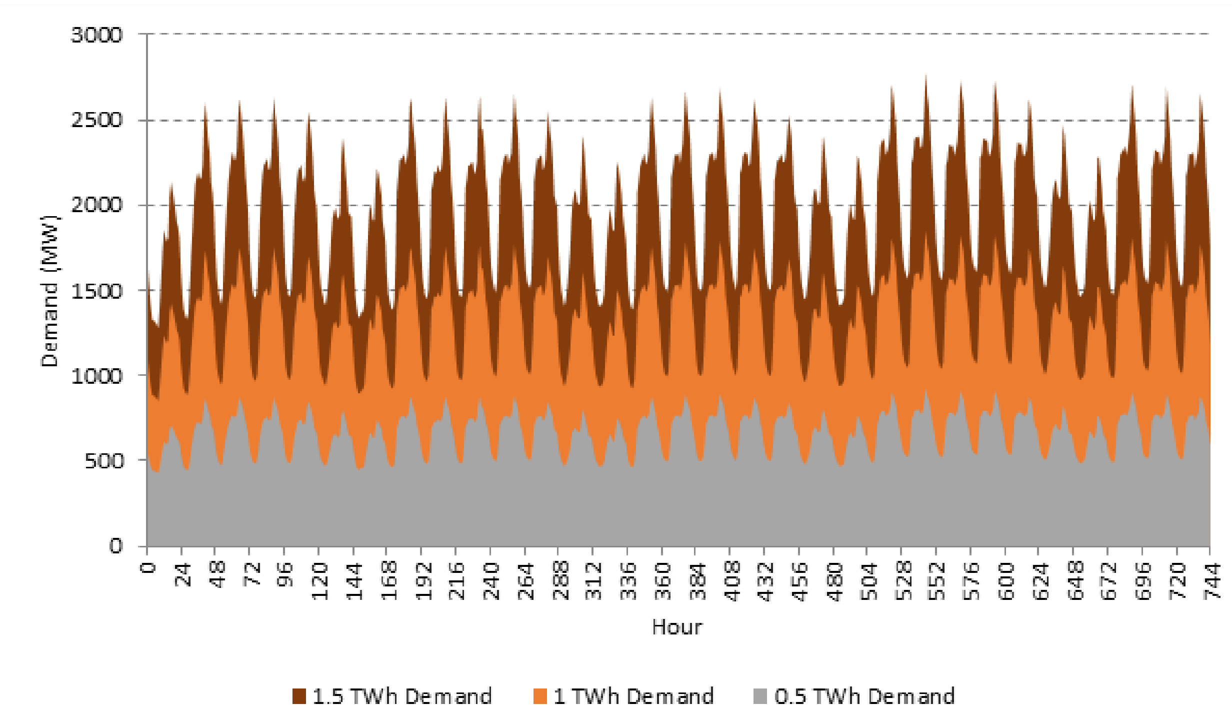


Figure 2: Distribution modified by the total Irish electricity demand required for January 2007 [8].

After describing the method for each distribution the authors attempt to validate the results based on case studies that have some existing data. It is very difficult to verify the hourly data produced in this study, since in almost all cases the hourly data is not available for a variety of reasons, such as 1) it is not measured, 2) it is not publicly available or 3) it is measured at an individual plant level and not at a national aggregation. As a result the validation is only done for the heat demand, wind power, solar photovoltaic, and solar thermal supply. For these validated distributions, the comparisons are made based on qualitative visual comparison as well as by carrying out a regression analysis comparing the two distributions in order to quantify the correlation. However the regression analysis is only used as an additional test where the visual test is the main comparison. The regression analysis cannot capture the distribution behaviour in which we try to compare such as long term trends and likeness. The regression analysis determines absolute correlation which is not necessary in the tests since we only need generic behavioural distributions during the year, we are not trying to replicate old data with the distributions, but rather we try to create model distributions for future application.

The electricity demand does not need to be validated since it is based on measured data from the various transmission system operators (TSOs) around Europe, while it is not possible at present to validate the cooling demand, transport demand, or wave power since no verified hourly production data could be obtained. In this way, the hourly distributions should be seen as a best estimate based on existing knowledge of what type of hourly variations can be expected in the future, rather than a recreation of what is being recorded today.

2.1 Demands

A different hourly distribution is typically required for each of the main end-user sectors: electricity, heating, cooling, and transport.

2.1.1 Electricity

Both the annual and hourly electricity demand is available and easily accessible for all EU countries and most European countries outside the Union. The annual electricity demand can be obtained from several sources like the International Energy Agency [9], national reports and the European Network of Transmission System Operators for Electricity [10]. Hourly electricity demand can usually only be obtained from two sources, either from the national TSO or, if the data is available for the modelled country, from the European Network of Transmission System Operators for Electricity [10]. For the purpose of this report the second option was used. The hourly data is publicly available online for all of the observed countries. Figure 3 demonstrates the electricity demand for Romania for the first week of January and June.

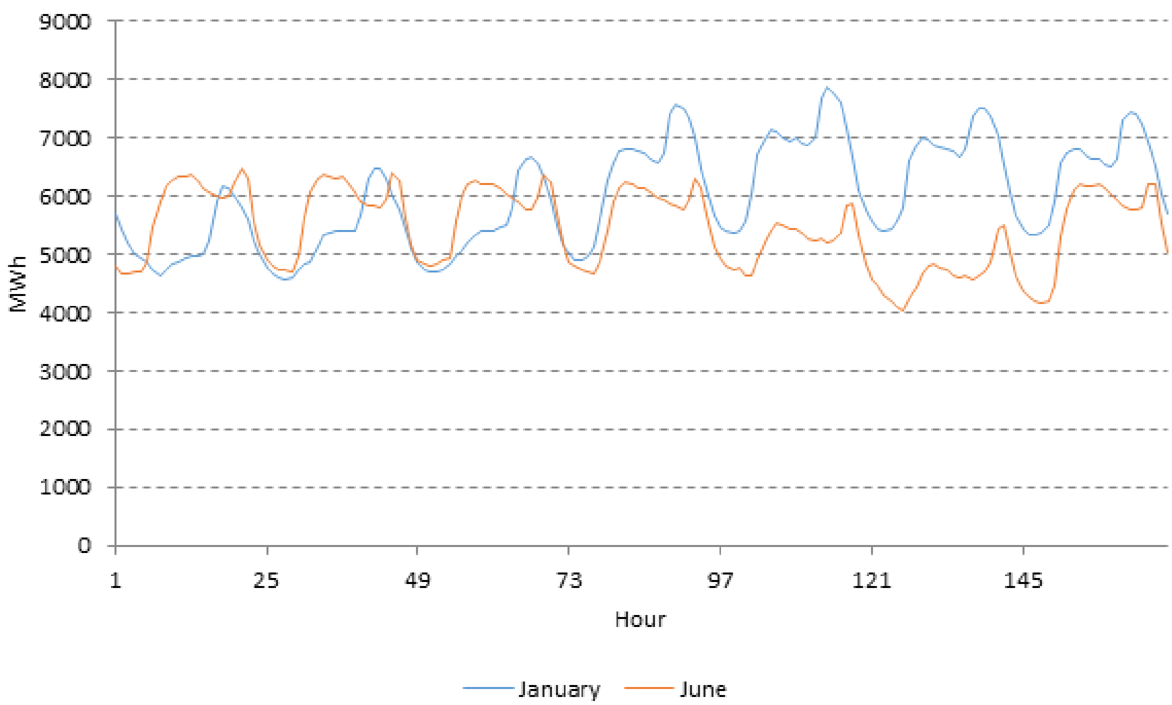


Figure 3 Hourly distribution curve for electricity demand

2.1.2 Heat

Hourly heat demand data is usually only available in countries with district heating systems and even in this case, it is usually not publicly available information. To overcome this, heat degree days (HDD) are typically used to evaluate variations in heating demands at different locations.

HDD are measured based on the outside temperature at a specific location. The temperature within a building is usually 2-3°C more than the temperature outside, so when the outside temperature is for example 15°C, then the inside temperature of a building is usually 17-18°C. Therefore, once the outside temperature drops below 15°C outside, then the inside temperature drops below 17-18°C and the space heating within a building is usually turned on. The outside temperature used to estimate the space heating demand, for example, in this case 15°C, is referred to as the set-point. HDD are calculated based on the difference between the set-point and the outside temperature, with the difference reflecting the amount of heat that is required at that time [11, 12]. To create an hourly distribution, the same methodology is applied for each hour of the year by comparing the temperature measured outside with the set-point. If the outside temperature is above the set-point, then the HDD for that hour is assumed to be zero. As a result, the results are very sensitive to the set-point that is assumed. Different values are typically used depending on a number of factors such as the climate and the typical level of house insulation in the area [11].

Space heating is usually not required during the summer months of the year, since the heat absorbed during the warm days and hours is enough to keep the buildings warm during colder periods. Once again, this is evident on district heating systems, as their operators often shut down the supply of space heating in the summer months. For example, district heating systems in the Czech Republic usually stop supplying space heating for June, July and August (see Appendix A). When the hourly distribution is created based on outside temperature data, there can be some hours in the summer where the outside temperature is above the set point, even though it is very unlikely that people use their heat systems during these hours. To account for this, the space heating demand is set to zero for all hours outside of the typical heating season. The result is an hourly distribution of space heating which can be replicated for any location in the world that records outside temperature, which is very common and publicly available information. However, HDD only represent variations in the hourly space heating demand (SH_H) and not in the hot water demand.

Hot water is required for cooking, cleaning, showering, and bathing in buildings. Unlike space heating, hot water demands do not vary significantly over the year. This is evident during the summer months on district heating systems, when the space heating is switched off and the only demand being met is hot water [13, 14]. Based on these experiences, it is assumed here that hot water is a constant demand over the entire year. The demand for hot water is estimated here by identifying what percentage of the total annual heat demand, TH_Y, is hot water, $HW_{Y\%}$. This data is currently available from the ENTRANZE database [15]. This total demand for hot water is then evenly distributed over each hour of the year, to identify the hourly demand for hot water, HW_H. It is assumed that each hour in the year has the same constant demand for hot water. This can then be added to hourly space heating demand, SH_H, developed with the HDD data, to provide an hourly distribution for the total heat demand (TH_H).

$$HW_H = \frac{\frac{SH_Y}{1 - HW_{Y\%}} \cdot HW_{Y\%}}{h} \tag{1}$$

This methodology has been applied to the five EU member states based on the assumptions outlined in Table 2. An example of the resulting hourly distributions is presented in Figure 4 for the United Kingdom, demonstrating the short-term hourly variations that occurs over the year.

Many of the extreme changes are concealed if hourly data is replaced with daily average, as displayed in Figure 5, outlining the importance of hourly considerations when simulating the heating sector.

Table 2: Assumptions for the hourly heat distributions developed in this study to apply the methodology.

Country	Space Heating Assumptions	Hot Water Assumptions			District heating distribution
	Set-point (^{O}C)	Heating Season	Annual Hot Water Demand (% of total heat demand)	Resulting Ratio of Peak to Baseload Demand (from equation 1)	Network Losses (% of annual heat production)
Croatia	16	15th September to 15th May	16%	22	14%
Czech Republic	16	Conditional: see Appendix A	18%	15	16%
Italy	16	All Year: see Appendix A	13%	34	n/a (assume 15%)
Romania	16	Conditional: see Appendix A	28%	14	19%
United Kingdom	16	1st October – 30th April	20%	15	n/a (assumed 15%)

Finally, when this heating distribution is used to model future heating scenarios, it is likely that heat savings will need to be taken into account due to measures such as better insulation, doors, and windows. In these future scenarios, the relationship between space heating and hot water demands will need to be recalculated based on the new demands after these savings are implemented.

These hourly distributions represent the heat demand in the building, so it does not reflect the demand for heat from a district heating system. If an hourly profile is required to represent the demand form district heating plants, then network losses must also be considered. These are added as an additional baseload demand in the same way as hot water, but this time using the annual network losses over the year. Typically these network losses are in the region of 15% [16], but can sometimes be calculated for different countries from annual energy balances [9]. As displayed in Table 2, the data required is not always available to do so.

In order to validate the methodology used for the creation of the heat demand distribution, hourly values for a district heating plant in Italy have been used. Using the method described above a calculated hourly heat distribution was calculated for Italy. This calculated demand is compared with the reference real world demand.

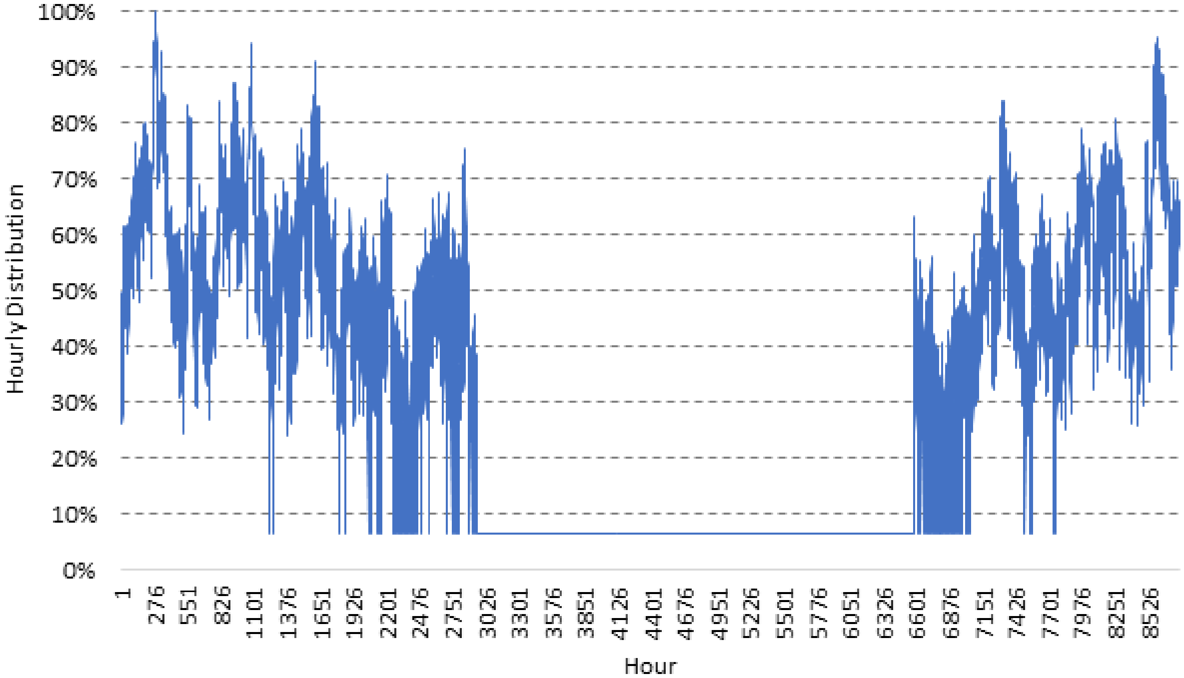


Figure 4: Hourly heat demand distribution for the United Kingdom.

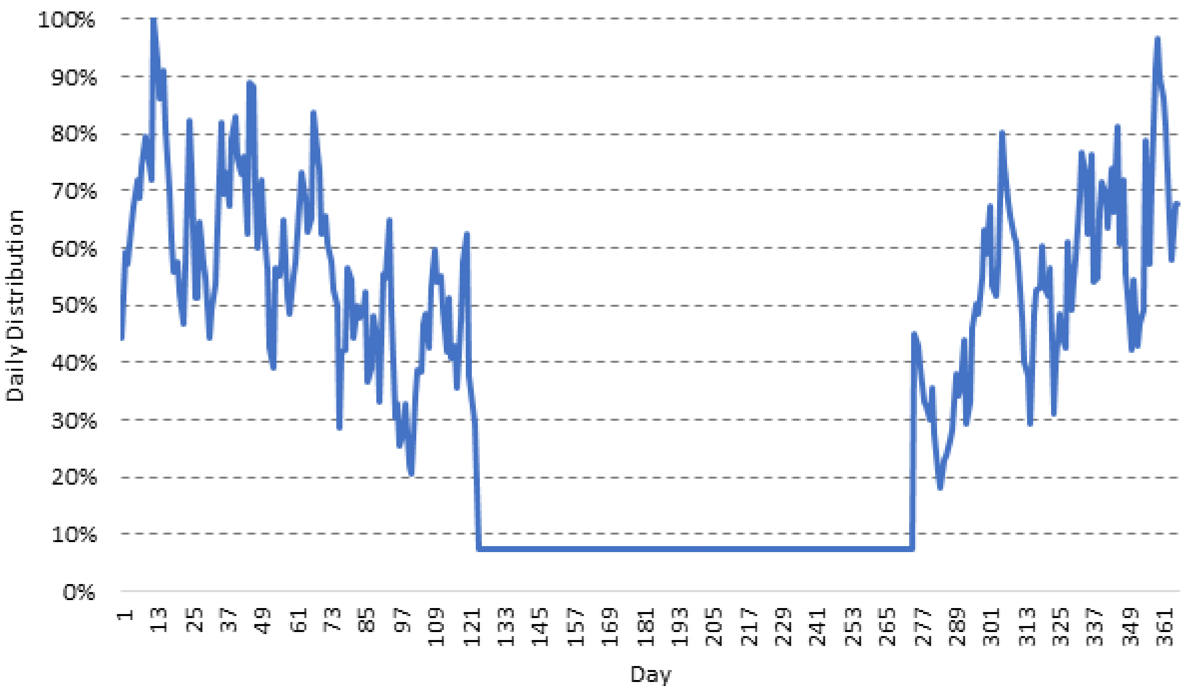


Figure 5: Daily heat demand distribution for the United Kingdom.

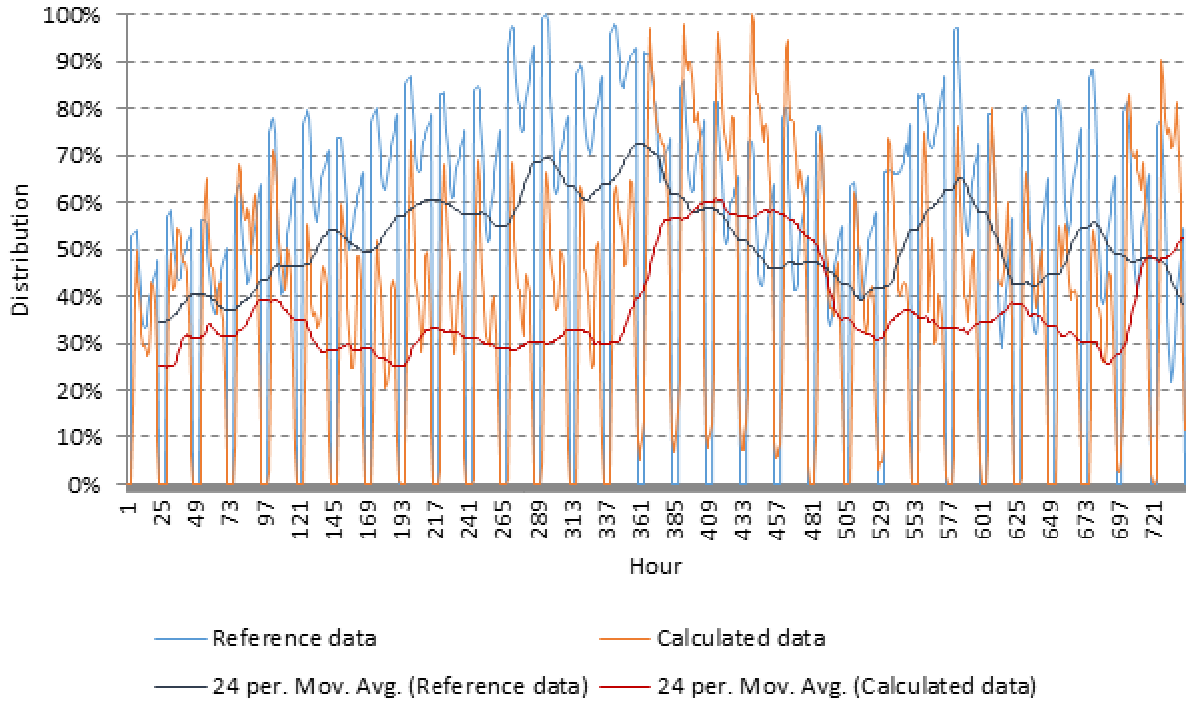


Figure 6: Comparison of reference and calculated heat demand in Brescia in Italy for January 2012.

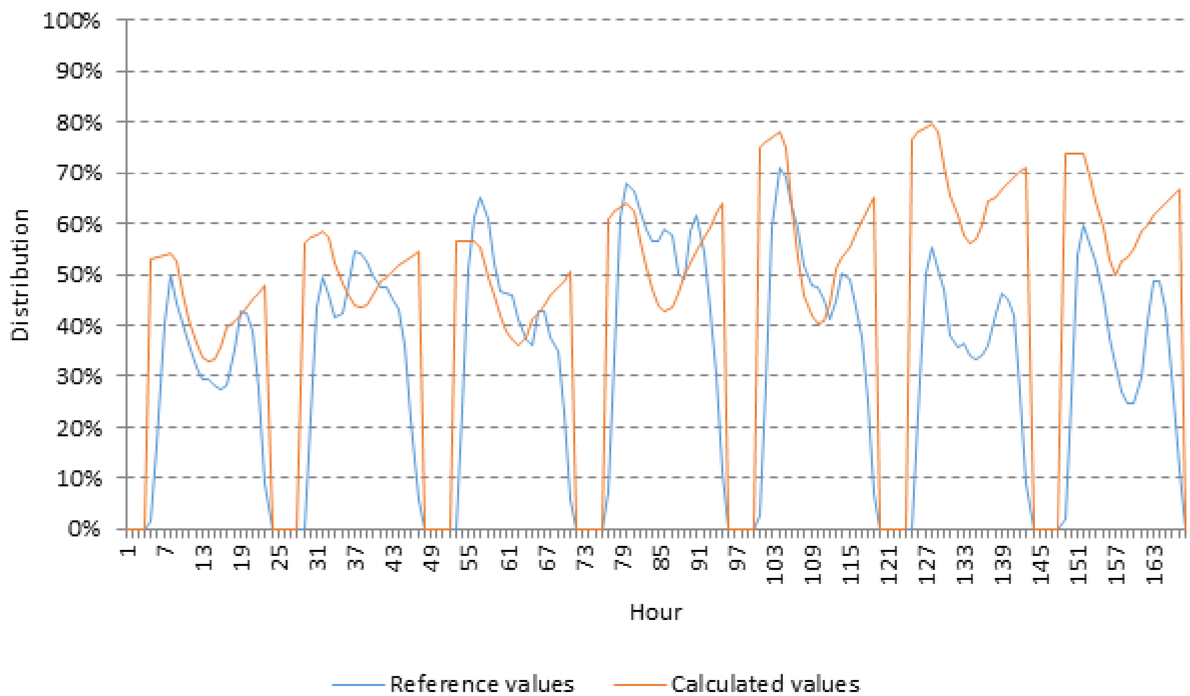


Figure 7: Hourly comparison of the heat demand on an Italian district heating system. The identity of city cannot be revealed due to a data confidentiality agreement.

Figure 6 shows the heat demand in January 2012 (744 hours) for the calculated and reference distributions, on an hourly basis. The 24-hour moving average is also shown for both distributions. The reference distribution is based on heat demand in Brescia in Italy for the year 2012. In order to compare the two curves, the original data provided by the district heating plant had to be separated into the hot water and space heating demands. The calculated hourly distribution also had to be modified in order to accommodate to the heating regulations of Italy where the heating is active from 05:00 to 23:00 (see Appendix A: Typical Heating Season in each STRATEGO Country). The results show that there is some correlation between the hourly distributions with an R2-value of 0.36.

Figure 7 demonstrates the comparison between the reference and the calculated data sets for the first week of January (168 hours). It can be seen that the two data sets follow similar trends, with a slightly higher difference in the last two days. The R^2-value comparing the two distributions is 0.44. This is because the peaks and troughs during the period are at slightly different times and locations in the figure.

2.1.3 Cooling

The cooling distribution is created using a similar methodology as the heating distribution. The Cooling Degree Days (CDD) are estimated using the same approach as HDD, but the set-point is usually different and the cooling demand occurs when the outside temperature is above the set-point, rather than below. The key challenge when applying the CDD methodology to create an hourly distribution is the lack of knowledge about cooling demands. Today cooling is mostly provided using air-conditioner units (heat pumps) that consume electricity. As a result, cooling demand is usually measured in terms of how much electricity is consumed by these air-conditioning units, rather than based on the cooling demand within the buildings. The only true measure of cooling demand is available from district cooling networks, but currently there are relatively few large-scale district cooling networks in place. In total there are approximately 100 district cooling systems in Europe, but these are still relatively small compared to the overall demand: in 2009 the verified district cooling demand was approximately 9 PJ compared to a total cooling demand of approximately 700 PJ in Europe [13]. It was not possible to obtain hourly demand data from the existing district cooling systems during this work, but general characteristics of cooling demands have recently been reported by Frederiksen and Werner [13] and also in the RESCUE project [17].

The RESCUE project analysed hourly cooling demand from approximately 50 buildings spread across different district cooling systems in Europe. Surprisingly, their results indicated that the demand for ‘comfort cooling’ began at temperatures as low as 9^{O}C, and became fully linear to ambient temperature at approximately 15-17^{O}C. As a result, the set-point for estimating the district cooling distribution should be in this region when calculating the CDD.

The RESCUE analysis also indicated that on average 56% of the cooling demand was identified as baseload (i.e. non-weather dependent) [17], indicating that very large proportions of cooling are required throughout the year. This is likely due to the high number of services buildings that make up the cooling demand, which require cooling for non-weather dependent applications such as offices and IT applications. The non-weather dependent share can be used in the same way as the hot water share for heating in equation 1.

Table 3: Assumptions for the hourly cooling distributions developed in this study to apply the methodology.

Country	Space Cooling Assumptions		Baseload Assumptions	
	Set-point (^{O}C)	Peak Cooling Demand (% of peak after CDD methodology)	Annual Baseload Demand (% of total cooling demand)	Resulting Ratio of Peak to Baseload Demand (from equation 1)
Croatia	17	100%	56%	7
Czech Republic	16	100%	56%	13
Italy	17	100%	56%	7
Romania	17	100%	56%	10
United Kingdom*	15	85%*	56%	10

*A peak was removed from the UK data since it was considered an outlier: it represented a day where the average temperature from the six locations across the UK was 29˚C, primarily due to a temperature of 39˚C recorded in Glasgow. This is an extremely high temperature for the UK so it is unlikely that cooling units will be designed to meet this once-off peak demand.

Once again, this methodology is applied here to the five different countries using the key assumptions outlined in Table 3. The set-point was varied between the countries depending on their climate since it is assumed that the buildings in warmer countries have better natural cooling than the buildings in colder countries. This was monitored by calculating the ratio between the peak cooling demand and the baseload cooling demand during the year. Data reported by Frederiksen and Werner for the district cooling system in Helsingborg (Sweden) indicates that this ratio is approximately 8 [13], and hence a similar scale was purposely maintained here. An example of the resulting hourly distribution is presented in Figure 8 for the Czech Republic. As expected the cooling demand is baseload during the winter months and peaks in the middle of summer. Once again, the hourly distribution in Figure 8 displays much larger variations than the daily distribution equivalent displayed in Figure 9. Many buildings use electricity to supply this cooling demand so accounting for these variations is important for the short-term balancing of the electricity grid. If district cooling is used instead of electricity to meet the cooling demand, then district cooling network losses of approximately 10% of the annual district cooling production should be added [13]. Validation for the cooling distribution method is not possible in this study due to a lack of reference data.

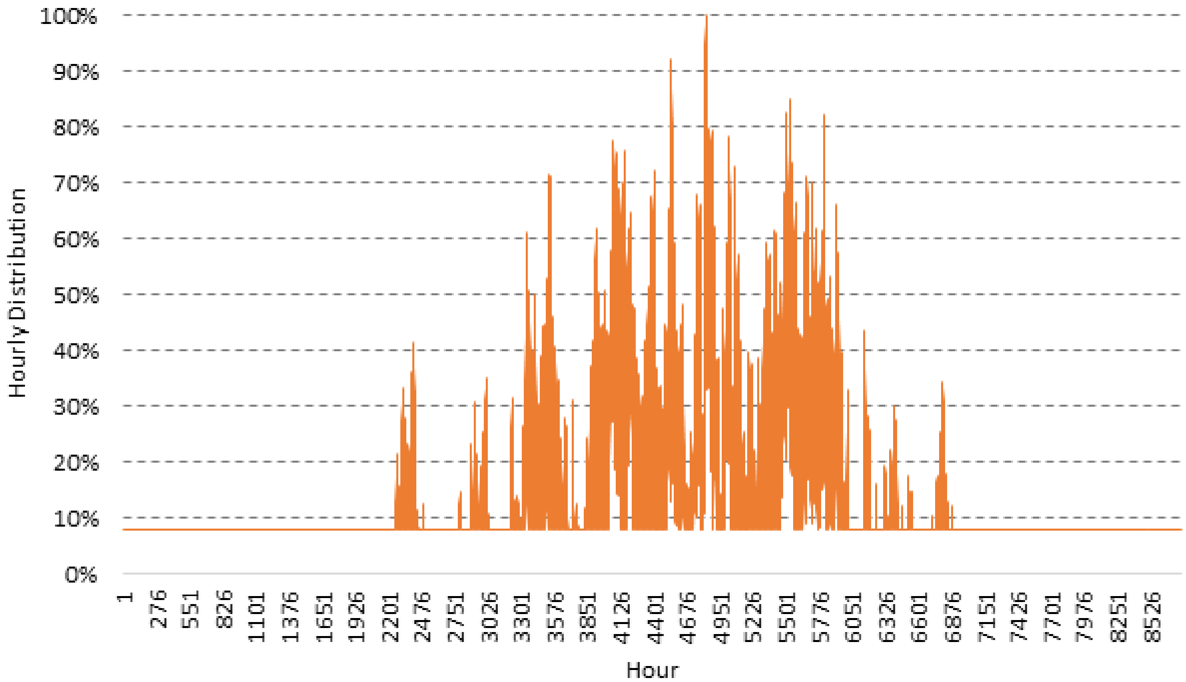


Figure 8: Hourly cooling demand distribution for the Czech Republic.

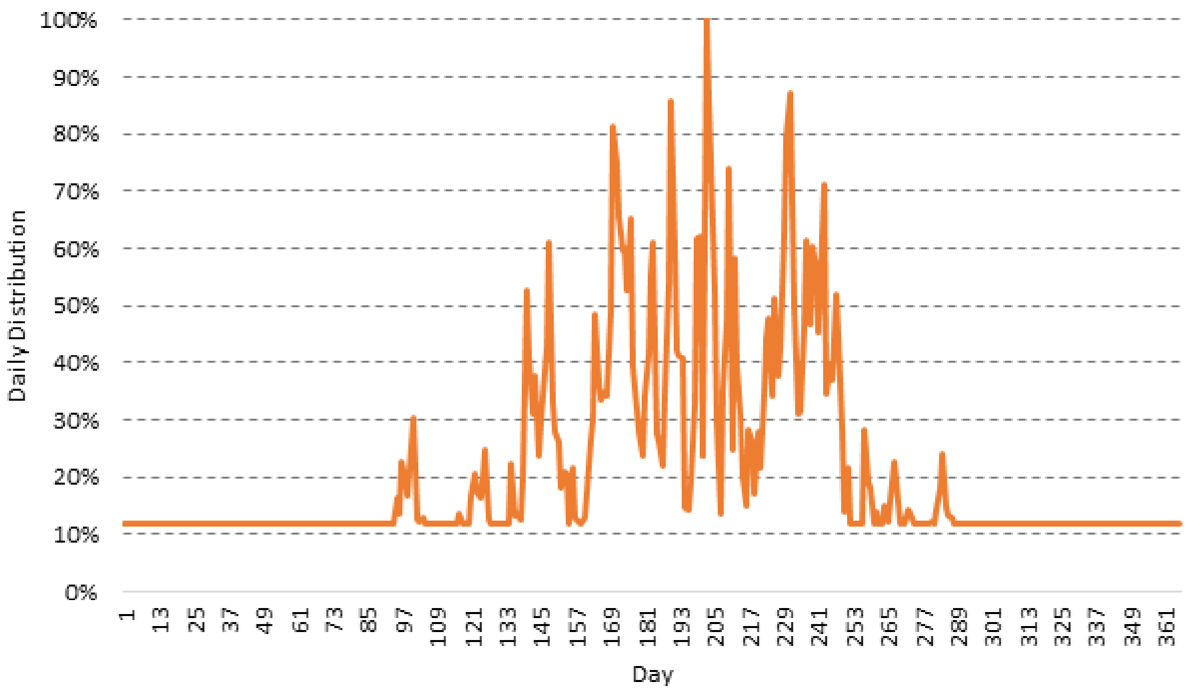


Figure 9: Daily cooling demand distribution for the Czech Republic.

2.1.4 Transport

A variety of approaches for the creation of annual energy consumption of the transport sector have already been described in the past [18-20]. Hourly data is usually more difficult to obtain, especially data adequate for energy planning. The agent based modelling (ABM) tool MATSim [21] has been used in this work for this purpose. The hourly distribution curve for the energy consumption of the transport sector has been created based on a case study for Croatia. MATSim is a data intensive tool requiring a broad range of input data from demographic information, activity plans, detailed transportation network and the definition of facilities. The created case study has been focused on Croatia's four largest cities namely Zagreb, Split, Rijeka and Osijek which together encompass the majority of the total population. The quality of the obtained results is very sensitive to the quality of the provided inputs. The best possible would be if each single agent represented one surveyed person, but this would be highly impractical and the data would be impossible to get. Therefore the inputs have to rely on surveys conducted amongst a limited number of participants and set of data that is usually available in an aggregated form. In order to reduce the number of input data and simplify the preparation of MATSim inputs some assumptions had to be made. The only two activities foreseen by the model are work and home and there are no holydays throughout the year. Figure 10 represents the distribution of work and home locations for the four modelled cities and the created network.

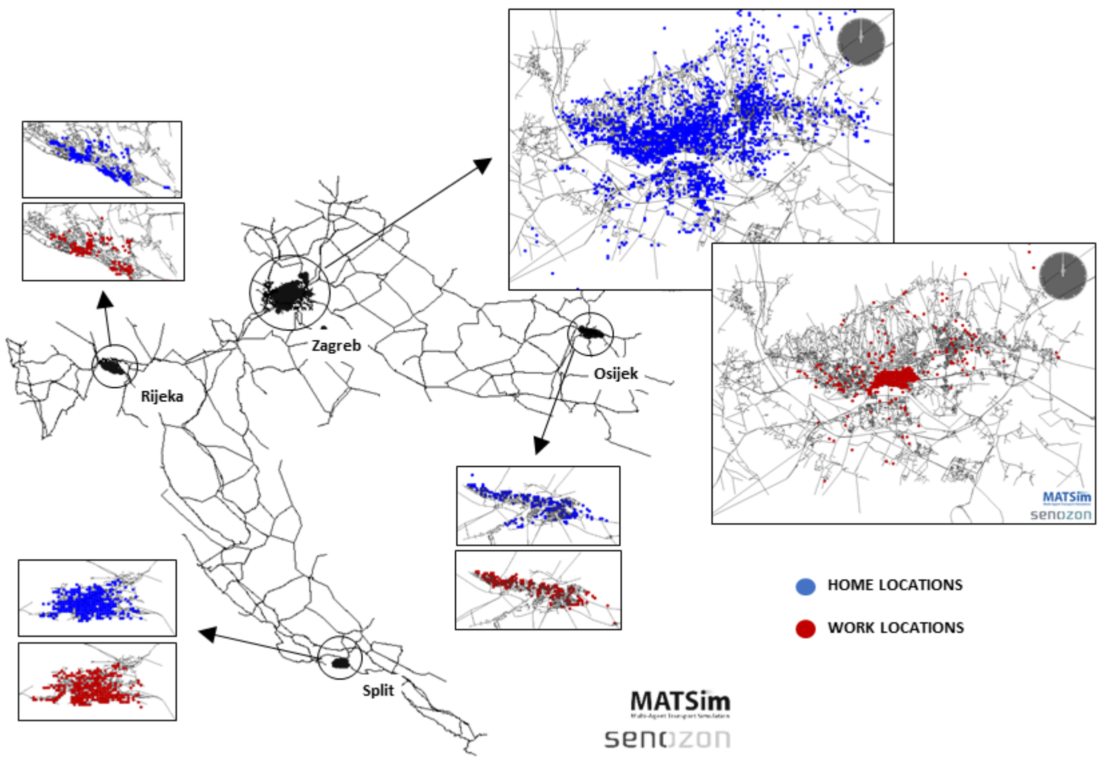


Figure 10: Distribution of home and work locations.

The detailed explanation of the methodology is available in our previous work [22]. The obtained distributions for the four individual cities as well as the aggregated curve are presented in Figure 11. It is not possible to validate the transport distribution method in this study due to a lack of data.

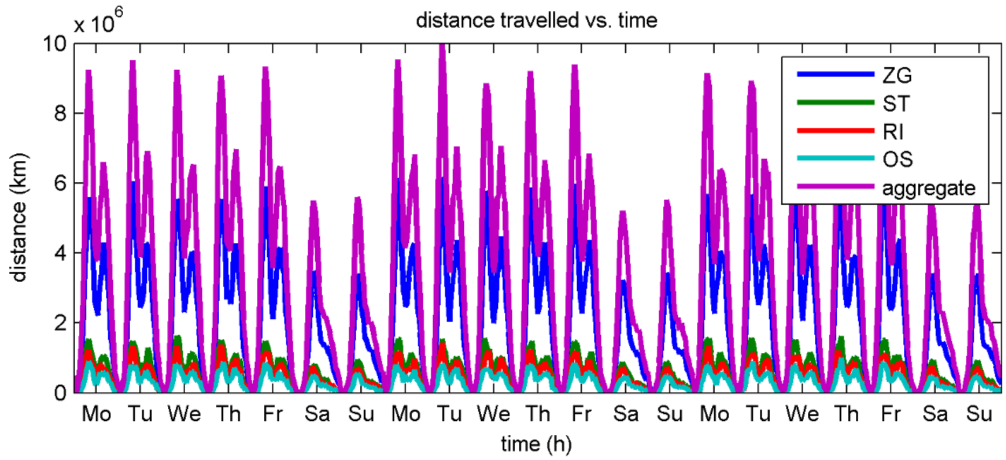


Figure 11: Hourly distribution of energy demand in transport.

2.2 Supply

Hourly distribution files are developed for three different types of renewable resources: wind, solar, and wave power. For solar, both solar PV and solar thermal are created separately.

2.2.1 Wind Power

In order to create an hourly distribution of electricity production from wind, hourly wind speed data has to be gathered first. These data can be obtained from measurements, computer tools like Meteonorm [23], national databases [24, 25] or similar sources.

For the purpose of this work, hourly wind speeds for one year have been gathered for six locations within every modelled country using the Meteonorm tool [23]. If we take the UK as an example, the data has been collected for Belfast, Bristol, Cardiff, London, Edinburgh and Glasgow. The gathered values represent hourly wind speeds at an elevation of 10m above ground. Figure 12 presents the gathered raw data for the six selected locations in the UK for the first week of July.

In order to utilize the gathered data in an energy system modelling tool such as EnergyPLAN, the wind speeds had to be converted into energy production. To accomplish this, power curves for three different wind turbines have been used, one 2MW turbine at an elevation of 80m and a 3MW and a 5MW turbine at elevations of 100m. Power curves of different wind turbines are readily available online [25-27]. The three utilized power curves are presented in Figure 13. Equation 2 has been used to calculate the wind speeds at the elevations of 80m and 100m based on the ones collected from Meteonorm.

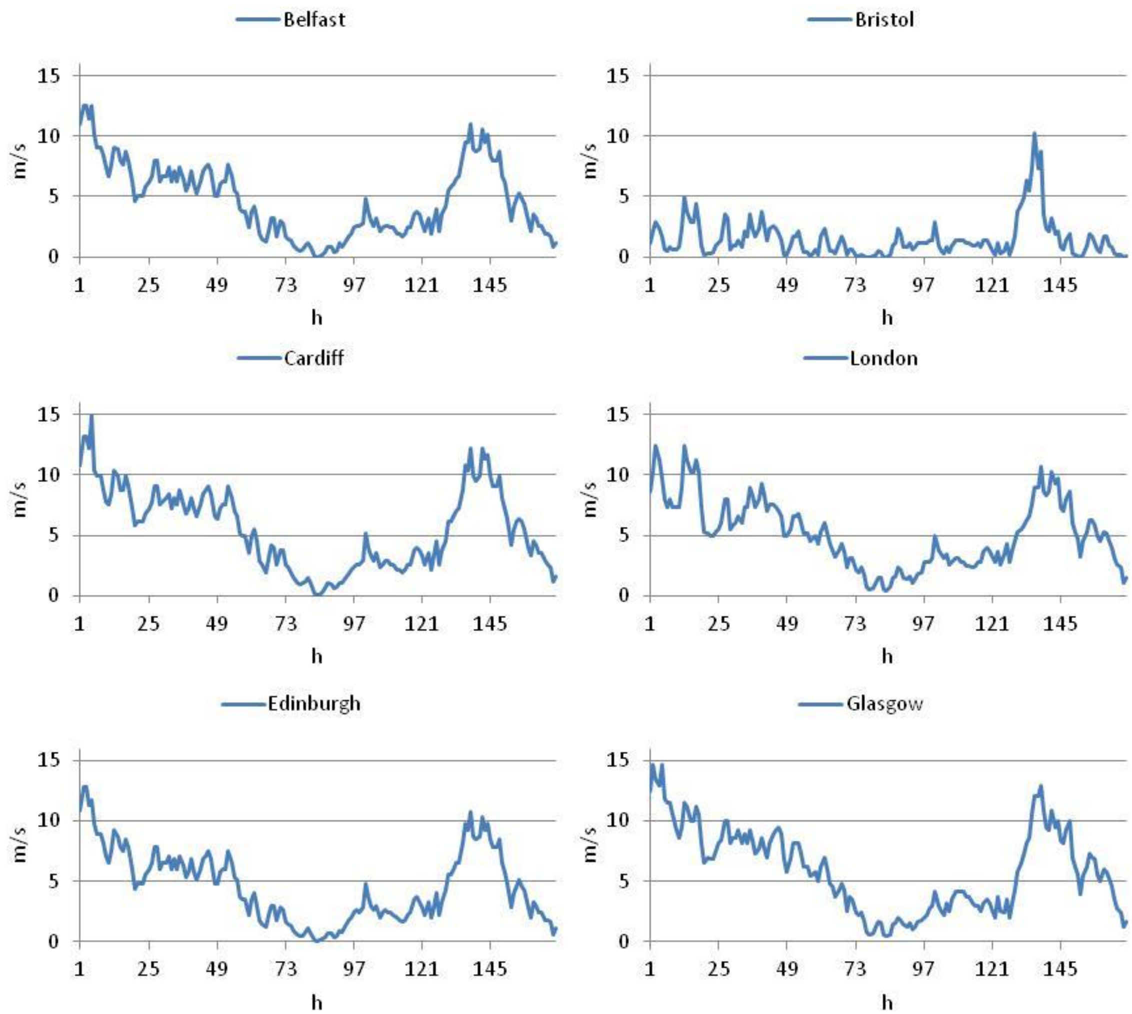


Figure 12: Raw wind speed data.

Using Equation 2 and the presented power curves, the electricity production for every individual location is calculated. The aggregated distribution curves for the whole countries are then calculated as an average of the six individual ones. Figure 14 presents the average wind speeds at 100m and the aggregated distribution curve for electricity production from wind for the UK for the first week of July.

$$
\begin{aligned}
& ws_h = ws_{10} \cdot \left(\frac{h}{10}\right)^{\alpha} \\
& \mathrm{ws}_h - \textit{wind speed at desired height}\left[m/s\right] \\
& \mathrm{ws}_{10} - \textit{wind speed at } 10m\left[m/s\right] \\
& h - \textit{height at which the wind speed is being calculated}\left[m\right] \\
& \alpha - \textit{roughness of terrain coefficient}
\end{aligned}
\tag{2}
$$

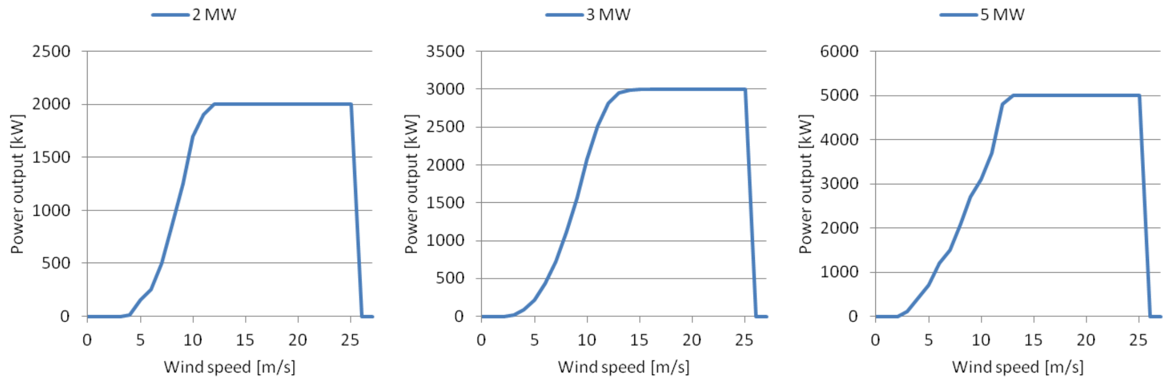


Figure 13: Power curves for different wind turbines.

Electricity production from offshore wind power is handled in much the same way with the exception that offshore wind data is used and there is less available data for these cases. Data measured on islands, offshore platforms or buoys has been used here. If we take Italy as an example, the offshore wind data for 4 locations has been used. The hourly data has again been recalculated to fit the necessary heights and the appropriate power curves have again been utilized to calculate the electricity production. Figure 15 presents the average wind speeds and the aggregated electricity production curve for the four available locations in Italy for the first week of June.

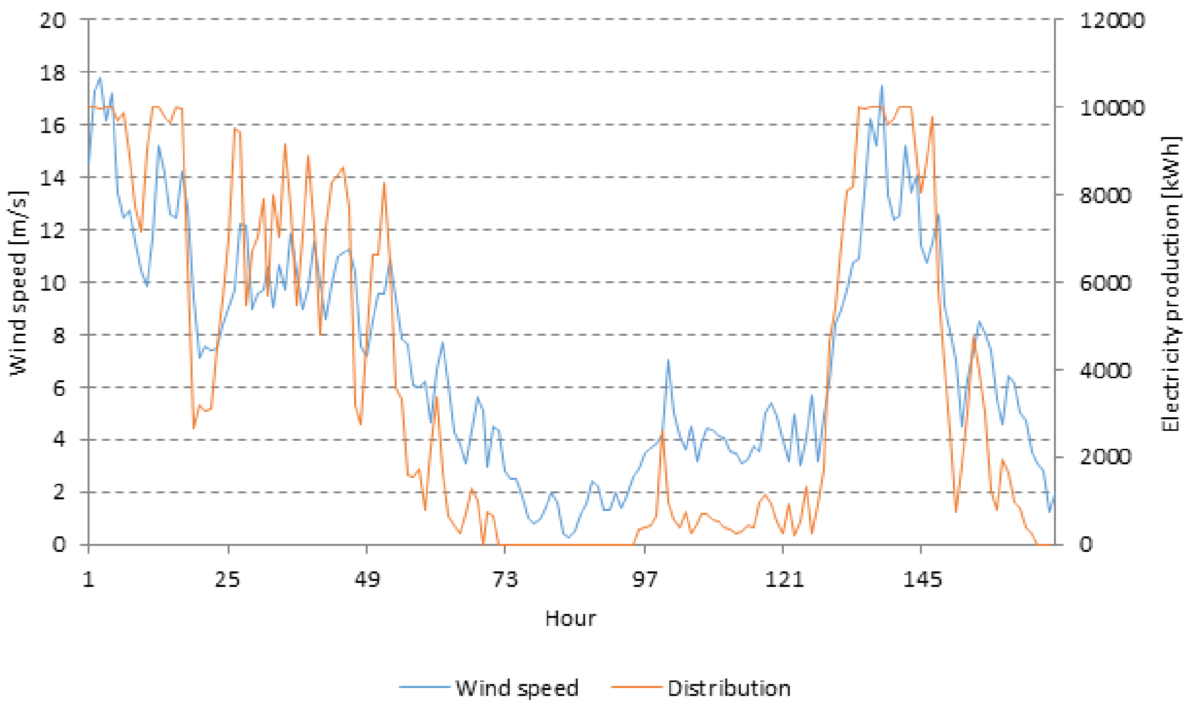


Figure 14: Comparison of the average wind speed and aggregated distribution curve.

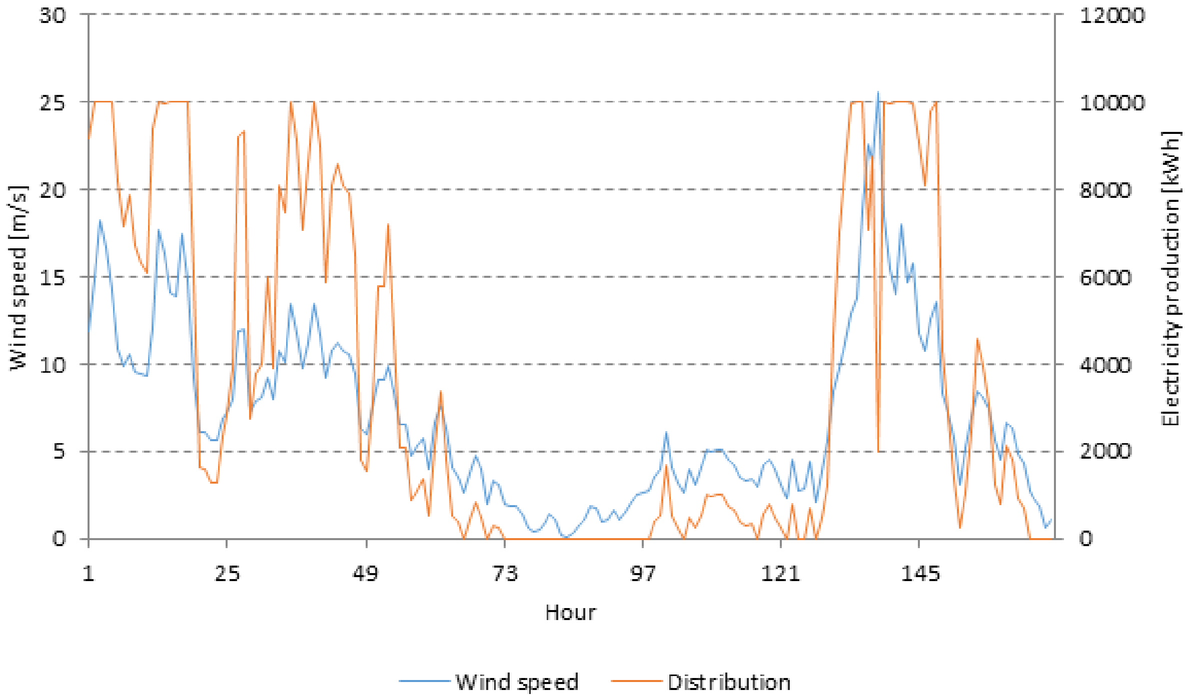


Figure 15: Comparison of offshore wind speeds and the aggregated distribution curve.

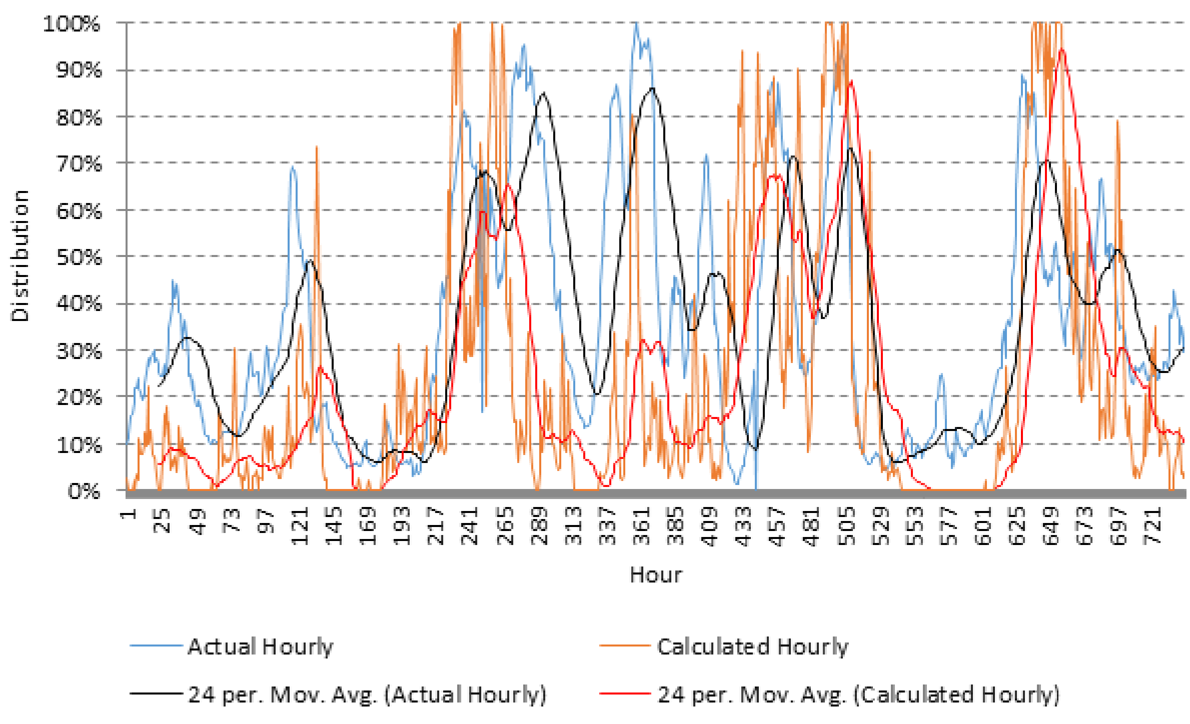


Figure 16: Comparison of actual wind electricity generation with calculated generation for January 2010 in the UK (excluding Northern Ireland).

The UK is used as a case study to validate the wind power distribution. To validate the accuracy of the calculated distribution with actual real world electricity generation, data was extracted from the Elexon database [28]. Elexon is involved in the operation of the wholesale electricity market in the UK. They collect 5 minute interval electricity generation for wind for the UK, excluding Northern Ireland. Figure 16 below compares a calculated distribution with the Elexon data on an hourly basis in January 2010. A moving average over 24 hours is also shown for each distribution. This shows the daily trend and this distribution is used for the comparison. January was selected because later in 2010 numerous wind farms began operation and this skews the comparison. This is because when the distribution is calculated, the total electricity capacity for that year is included from January to December, even if the capacity was not operating in January.

As shown in the figure, on a 24 hour moving average distribution the areas where there are peaks and troughs in wind production is relatively similar between the distributions. The R^2-value comparing the two 24-hour distributions for January is 0.38 showing that there is some correlation between the two distributions. This correlation is not higher since the peaks and troughs in wind occur at slightly different times and locations in the figure. But the important comparison in this study is that the general trend is followed even if at slightly different times. The hourly R^2-value over the month is 0,22, and this is also because the peaks and troughs do not match within the exact same hour, but the trend is similar.

2.2.2 Solar

When it comes to solar power there are two aspects that need to be considered, solar thermal collectors and photovoltaics (PV). The idea behind the generation of the hourly distribution of energy production from both is very similar. For the case of PV, the electricity output will match the solar insolation quite well. For this reason, hourly solar insolation is used to develop the hourly distribution. This data can be obtained from tools like Meteonorm [23]. The insolations are usually available for flat surfaces and tilted plains. The optimal slope and also the optimal azimuth of the surface for maximum annual solar insolation can be obtained from PVGIS for Europe and Asia [29].

The average insolation, and with that the average PV distribution curve, can be created as a combination of the two. For the Czech Republic as an example, solar insolations on flat surfaces and surfaces tilted to the optimal angle obtained from PVGIS have been collected for 6 locations using Meteonorm. The distribution is then created for every location individually as an average of the insolation on the tilted and flat planes. The aggregated distribution curve is calculated as an average of the 6 individual ones. The curves can be calibrated according to the calculated total annual electricity production varying the ratios between the two types of insolation (flat surface and tilted plane). The aggregated curve for the Czech Republic for the first week of January and July are presented in Figure 17.

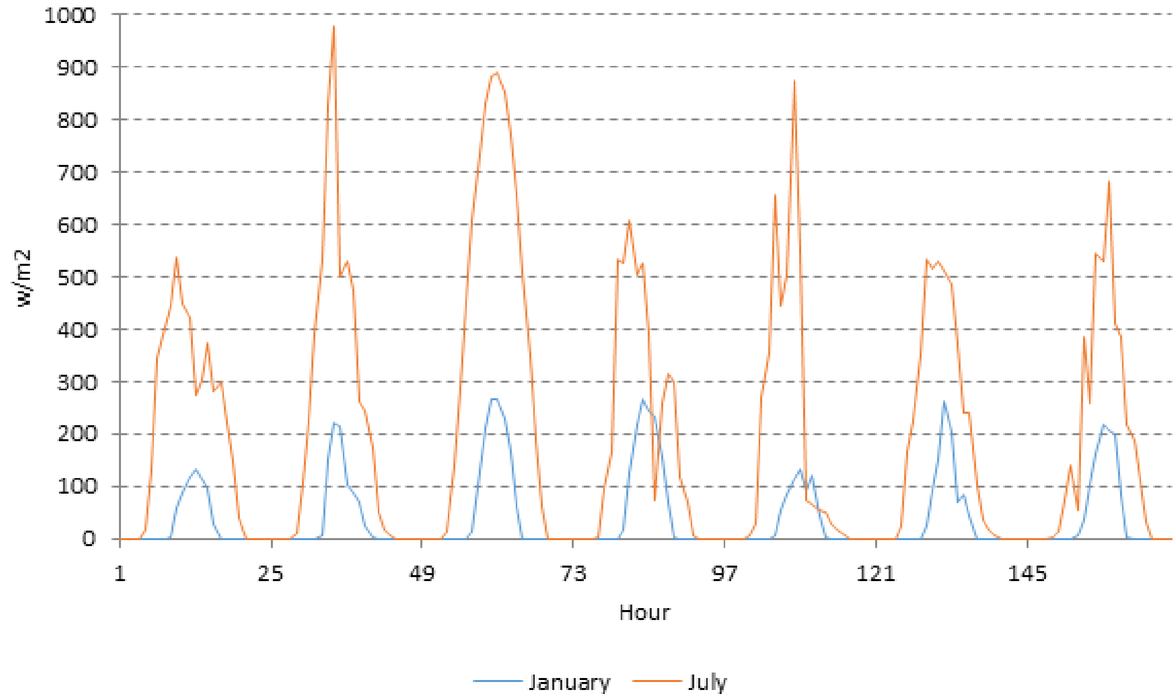


Figure 17: PV distribution for the Czech Republic.

The solar thermal distribution can usually be created the same way as PV if the tool used to model the system handles thermal storage separately from the hourly distribution curve. If the tool uses the hourly distribution of solar thermal production as an input into the energy storage and the heat demand as an output, for example as the tool EnergyPLAN does, the hourly distribution for solar thermal can again be modelled as a function of the hourly solar insolation on a flat and tilted surface.

In order to validate the methodology related to the distribution of energy production from PV, a calculated distribution was compared with actual real world electricity generation using German solar data. Real world data was extracted from the Amprion database. Amprion GmbH is a transmission system operator and operates the German extra-high voltage grid from Lower Saxony down to the Alps. Amprion collect solar production data every 15 minutes in West Germany. Data collected for Hanover and Frankfurt for the calculated distribution was compared with the Amprion data and this is shown in Figure 18 and Figure 21. Data was only available for the second half of 2010 (July 1 to December 31 2010).

In Figure 18 the hourly solar distribution is shown for the reference and calculated distributions. In addition, a moving average over one week (168 hours) is shown for each distribution in order to demonstrate the longer term trend.

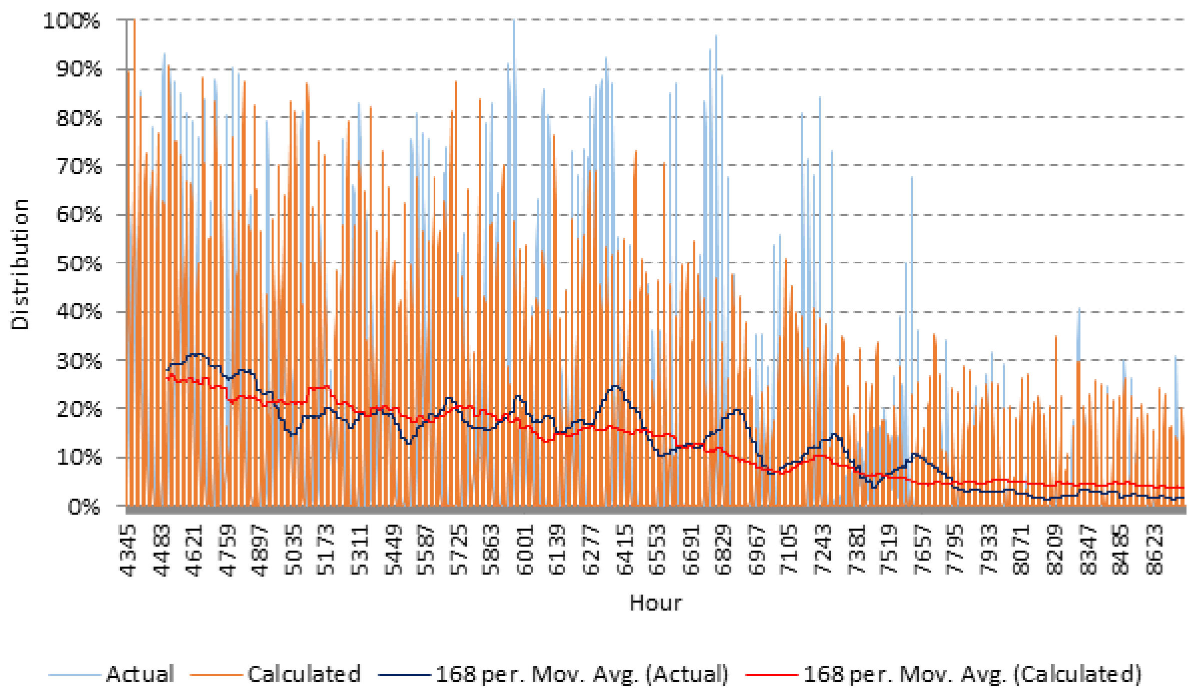


Figure 18: Comparison of reference solar electricity generation with calculated generation for July 1st to December 31st in 2010 for West Germany.

Overall the figure shows a general downward trend in solar production from July to December for both distributions. This is expected as the seasons shift from summer to winter. For the hourly distribution from July to December there is a similar trend and the R^2-value is 0.67, but there are some additional peaks in the reference distribution. Since the actual distribution includes most of West Germany and covers a broader area, the solar capacity is higher than compared with the calculated distribution which only includes two cities. But in general the trends follow each other and there are peaks and troughs occurring around the same periods. The weekly average production (168 hours) comparison shows a similarity between the distributions with an R^2-value of 0.83. If all solar data from this area in Germany was included in the calculated distribution (like it is in the Amprion dataset) then it is likely that the distributions would be closer.

The hourly distributions over the July month over 744 hours are shown in Figure 21 below. The R^2-value for the hourly comparison in this month is 0.55. As explained above, the peaks of the reference distribution are higher since the dataset covers a broader area in Germany and thus has a higher production capacity, increasing the peaks. But in general the trend is similar.

The methodology related to the creation of the solar thermal distributions has been validated on a case of the Marstal plant in Denmark. Hourly values for the solar heat available has been obtained from [30] and compared to the distribution created using the described methodology. It should be noted that hourly solar radiation values were not available for the exact location of the plant and the closest available point has been used, Sydfyns in Demark.

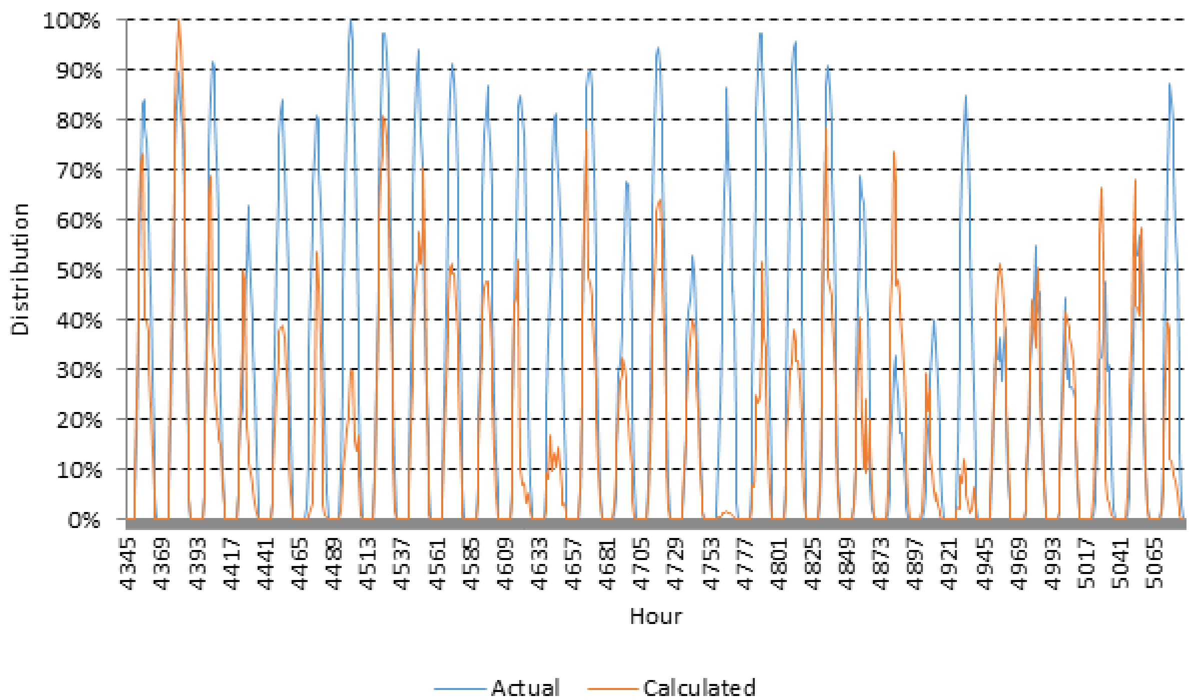


Figure 19: Comparison of reference solar electricity generation with calculated generation for July 1st to July 31st in 2010 for West Germany.

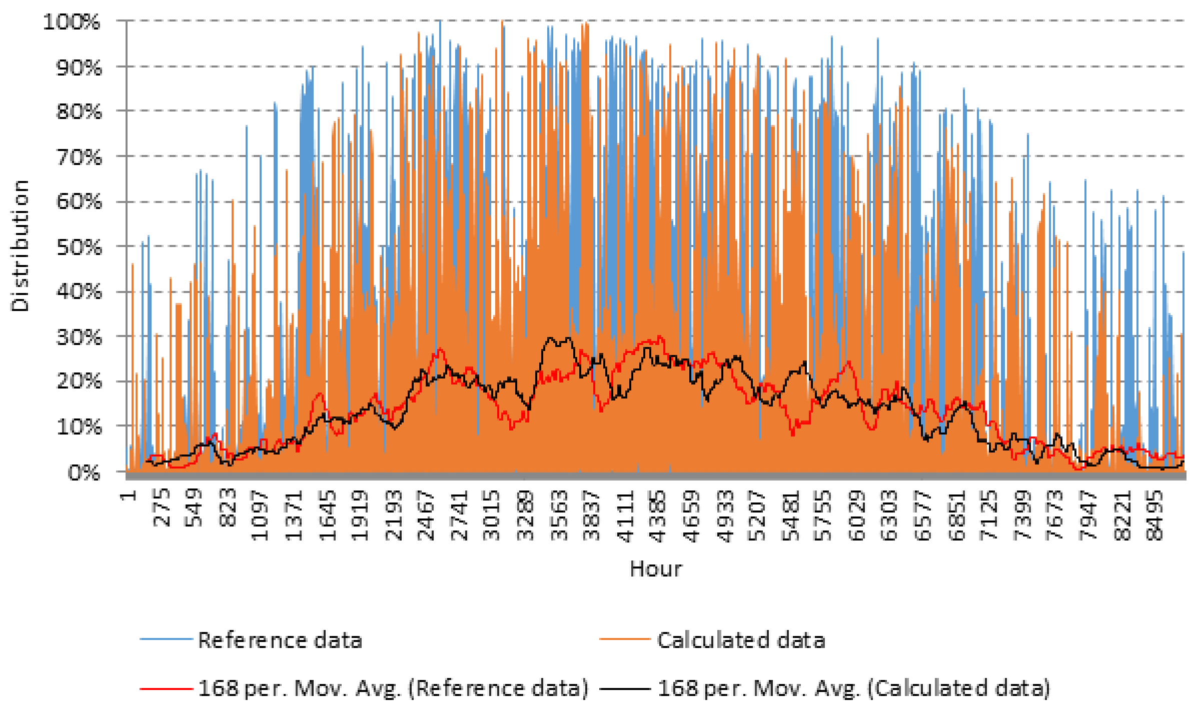


Figure 20: Comparison of reference solar thermal generation with calculated generation for 2010.

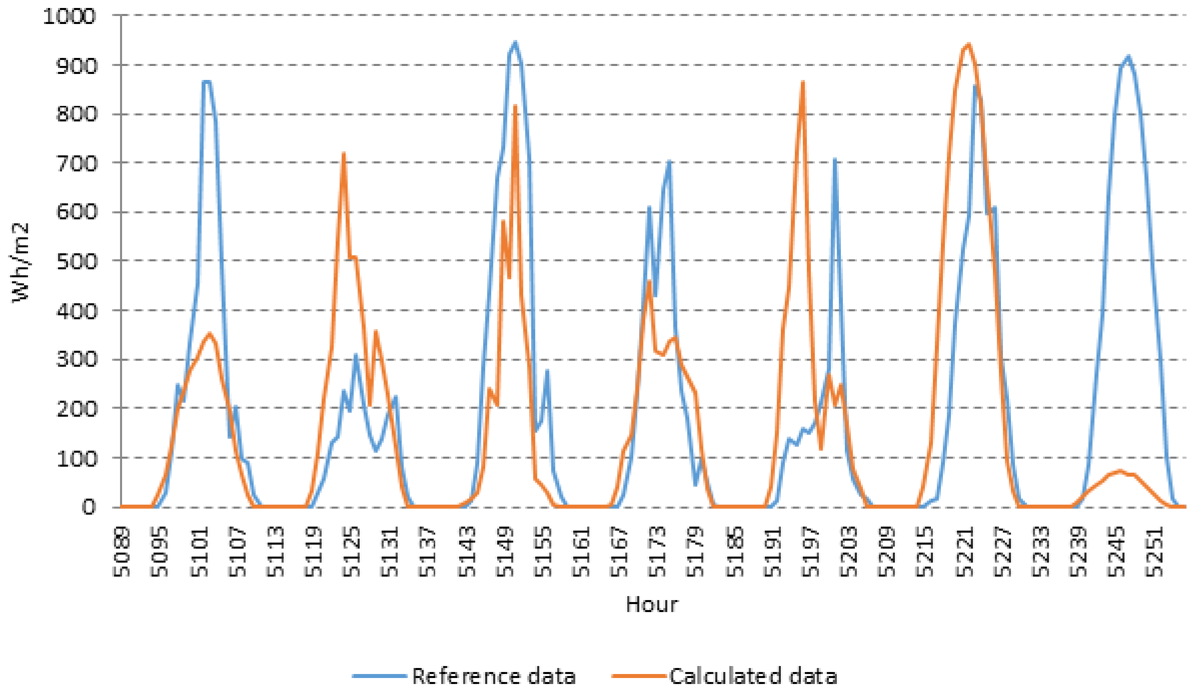


Figure 21: Hourly comparison of the reference and calculated distributions.

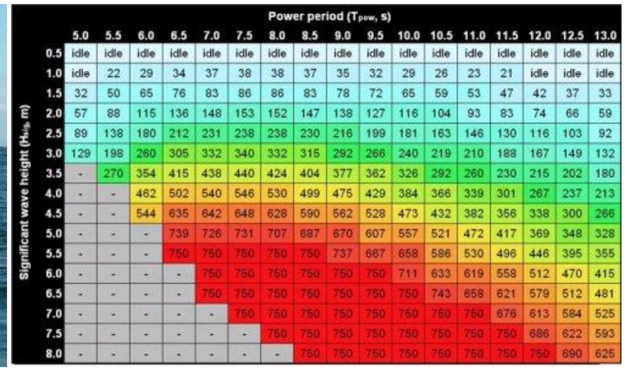
The hourly solar thermal distribution in 2010 is shown in Figure 22. The hourly distributions are shown along with the weekly moving average distribution over 168 hours.

It can be seen that the distributions over a weekly moving average are similar during the year with an R^2 value of 0.79. The R^2-value for the hourly distribution over the entire year is 0.42. The reason for this low value is due to the different timing and location on the figure of the peaks and troughs, but in general the trend is similar.

Figure 21 presents the comparison of the first week of August for the reference and the calculated data. The two data distributions demonstrate the same trends and similar peeks for most of the observed days. The R^2-value between the two hourly distributions is 0.3 showing a small correlation, due to different locations and peaks and troughs in the timing and figure. Greater differences can be noted in the first and the last day in the week. Overall the trend appears similar between the two distributions.

2.2.3 Wave Power

Unlike wind power where the three-bladed turbine has become the primary technology, it is very unlikely that there will be a standard design for future wave generators. This is due to the fact that wave power depends on two parameters: wave height and wave period. It is difficult to develop a wave generator that is able to operate across locations, since the relationship between these two parameters can vary depending on the local wave conditions.



Significant wave height (H_{sig}, m) \ Power period (T_{pow}, s)	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
1.0	idle	22	29	34	37	38	38	37	35	32	29	26	23	21	idle	idle	idle
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
2.0	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
3.5	-	270	354	415	438	440	424	404	377	362	326	292	260	230	215	202	180
4.0	-	-	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
4.5	-	-	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
5.0	-	-	-	739	726	731	707	687	670	607	557	521	472	417	369	348	328
5.5	-	-	-	750	750	750	750	750	737	667	658	586	530	496	446	395	355
6.0	-	-	-	-	750	750	750	750	750	750	711	633	619	558	512	470	415
6.5	-	-	-	-	750	750	750	750	750	750	750	743	658	621	579	512	481
7.0	-	-	-	-	-	750	750	750	750	750	750	750	750	676	613	584	525
7.5	-	-	-	-	-	-	750	750	750	750	750	750	750	750	686	622	593
8.0	-	-	-	-	-	-	-	750	750	750	750	750	750	750	750	690	625

(a) (b)

Figure 22: Pelamis wave generator (a) and its power matrix: output in kW (b).

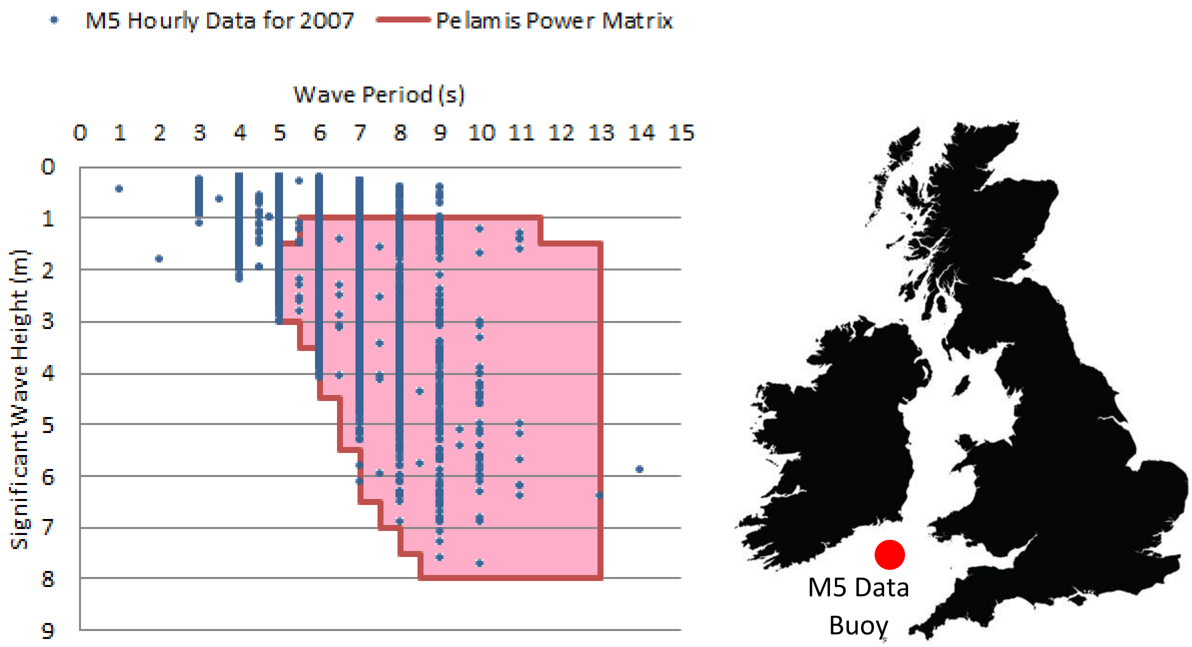


Figure 23: Scatter diagram for M5 data buoy off the coast of the United Kingdom. The data was gathered by the Marine Institute in Ireland [32].

Currently, the expected electricity production from a wave power device across a variety of wave periods and wave heights is reported using a power matrix [31]. For example, Figure 22 presents a wave power matrix for the Pelamis device. It is important to note that the wave height and wave period can vary and it is important to make sure that the data being measured is the same as required by the power matrix. For example, the wave period can often be the peak period (T_p), energy period (T_e), or mean period (T_z), while the wave height can often be the deterministic significant wave height ($H_{1/3}$), spectral significant wave height (H_{m0}), or maximum wave height (H_{max}).

When multiple power matrices are available, the suitability of the device for a particular site can be evaluated by completing a scatter diagram of the data. The hourly wave height and hourly wave period recorded at the site in question should be plotted against one another as illustrated in Figure 23. If the power matrix and recorded data from the site in question overlap each other significantly on the scatter diagram, then the wave energy generator being investigated is a good choice for that particular location. As seen in Figure 23, the Pelamis is a good match for the M5 site available here.

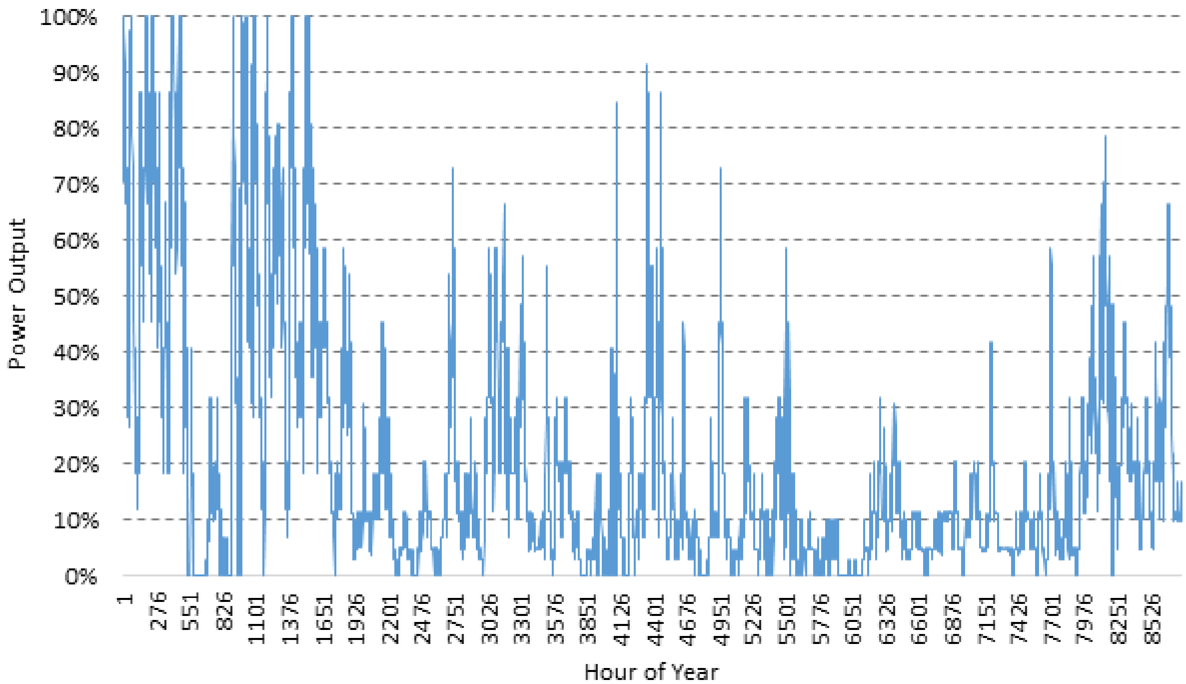


Figure 24: Hourly wave power output for the UK based on the Pelamis wave device (Figure 22) and wave data from the M5 data buoy (Figure 23).

Once the most suitable wave power device has been chosen, and the power matrix obtained, the hourly wave height and wave period data recorded at the site must be converted into an hourly power output. This was carried out here using a freeware tool developed as part of this study called WavePLAN, which can be downloaded as part of the EnergyPLAN tool [33]. An example of the hourly power production from the Pelamis wave device is provided in Figure 24. This curve represents the power for a single type of device at a single location. At present the key limitation for hourly wave power output is the availability of more hourly wave data across more locations. Additional data could not be obtained in this study since it was either unavailable or required a fee to be provided.

3 Discussion and Conclusion

In the future intermittent renewable energy will provide much larger shares of the primary energy supply and therefore this needs to be accommodated in future energy system modelling. The challenge is to determine how the energy demand and supply will fluctuate in the future. This study aimed to develop a methodology for developing energy demand and supply hourly distributions for different sectors of the energy system of a country. A methodology was developed for calculating demand and supply side distributions. The demand side included electricity, heat, cooling and transport. And the supply side included wind power, solar PV and solar thermal, and wave power.

Where possible the methodology was tested and validated using real world data compared with calculated data using the methodology. This was carried out for heat demand, wind power, and solar PV and solar thermal. Validation was not necessary for the electricity distribution, and for the cooling and transport demand it was not possible to validate since there is very limited real world data available.

Overall the validation showed that the main trends between the reference and calculated distributions were similar. There were variations between the distributions which are expected, but the main aim was to capture the key characteristics in the distributions over time, for example between seasons, in different weather events and in day-night shifts. Therefore, this methodology can provide a general picture of the short-term hourly variations that can be expected for supply and demand of a national energy system. However, if local bottom up data is available then it should be prioritised since there are differences between the exact values during each hour.

This is the first study of its type carried out for European countries and therefore the hourly distributions created using this methodology should be seen as a best estimate. The main purpose of the distributions is to determine what type of hourly variations can be expected in the future based on existing knowledge, rather than a recreation of what is being recorded today, which was done in the validation.

The methodology developed in this study has been used to calculate demand and supply distributions for five European countries in the Main Report of this STRATEGO project (UK, Romania, Italy, Czech Republic, and Croatia). Depending on the results from these countries the methodology developed in this may be refined further.

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Appendix A: Typical Heating Season in each STRATEGO Country

This information was collected from the local partners in STRATEGO.

Czech Republic

Two requirements need to be fulfilled to start delivering heat to customers:

1) The heating season is defined by law from 1st September to 31st May
2) Within this period, if the average daily outside temperature (at 7:00, 14:00 and two times at 21:00 hours) is below 13 degrees Celsius with stable weather forecast, then the district heating utilities starts delivering the heat. If the average temperature raises above 13 degree Celsius for 2 days (with stable forecast) then they stop delivering the heat.

Croatia

The heat season is usually from the 15th September to the 15th May.

Italy

Italy is quite a particular case in Europe regarding heating demand. While several north European Countries might be considered uniform regarding climatic zones, in Italy this cannot be the case. Its geography and extension in the north-south direction lead to a condition where cities located in the north require space heating for several months each year, while territories located in the south might not require space heating at all.

The operation of district heating in Italy is regulated by a law. The territory is divided into 6 climatic zones based on a degree days classification (degrees days are calculated considering 20°C as normal temperature):

- Zone A: territories presenting a number of degree-days not higher than 600
- Zone B: territories presenting a number of degree-days higher than 600 and lower than 900
- Zone C: territories presenting a number of degree-days higher than 900 and lower than 1400
- Zone D: territories with a number of degree-days higher than 1400 and lower than 2100
- Zone E: territories presenting a number of degree-days higher than 2100 and lower than 3000
- Zone F: territories presenting a number of degree-days higher than 3000

Space heating is permitted in each zone according to this calendar:

- Zone A: max 6 hours per day from December 1st to March 15th
- Zone B: max 8 hours per day from December 1st to March 31st
- Zone C: max 10 hours per day from November 15th to March 31st
- Zone D: max 12 hours per day from November 1st to April 15th
- Zone E: max 14 hours per day from October 15th to April 15th
- Area F: no limitation

The above permitted hours have to be between 5 am and 11 pm. For buildings connected to district heating (and other particular type of heating devices), the limitation regarding the max number of hours of daily operation does not apply. the limitation concerning the period of operation during the year is still applicable. If certain conditions apply, then the Mayor might extend the operating allowed period.

Romania

In Romania, the beginning of the period for district heating is considered after registration for 3 consecutive days, (between 06.00 pm - 06.00 am), the outside average daily air temperature of +10°C or less, but not later than November 1st.

Termination of district heating is done after 3 consecutive days in which the average outside air temperature exceeds +10°C, between 6.00 am, - 6.00 pm, but not earlier than April 15th.

United Kingdom

The heat season is usually from the 1st of October to the 30th April, usually beginning when a daytime peak temperatures of 16°C or less occurs for two or more consecutive days.