4.2. THETA THRESHOLD ANALYSIS FOR HOUR RESOLUTION

Each time step uses the previous lags to select the highest autocorrelated lag amplitude and compare it to the theta threshold, as shown in the flowchart in Figure 3.2. In this study, the goal is to compare the Autocorrelation Function (ACF) and Power Cepstrum as an autoregressive feature selector. To do this, it is necessary to determine the percentage of time steps using ConvLSTM for each type and month. The test is performed with 168 hours of previous lags for each time step, simulating the benchmark models for the hourly resolution. The months tested are those selected as the most predictable, March, April, May, and December. The full table showing the theta threshold used to test each type of autocorrelation calculation and the percentage of time step usage for each month. The results can be found in Figure 4.2.1.

		Month / Theta Threshold			
Type	% of Time Step Using ConvLSTM	March	April	May	December
Power_Cepstrum	90.00%	0.051446	0.050982	0.051921	0.050136
	80.00%	0.062307	0.057665	0.058908	0.061060
	70.00%	0.070363	0.063902	0.062649	0.074317
	60.00%	0.074829	0.069820	0.068355	0.082587
	50.00%	0.083827	0.076930	0.075410	0.089002
ACF	90.00%	0.571797	0.592953	0.549751	0.646807
	80.00%	0.584284	0.599591	0.577454	0.653260
	70.00%	0.592835	0.610852	0.595212	0.666220
	60.00%	0.601250	0.625570	0.610044	0.675272
	50.00%	0.609981	0.634244	0.622375	0.691317

Figure 4.2.1 Theta Threshold that will be used to teste for each type of autocorrelation calculation, each % of time step usage and for each month.

The analysis of the number of time steps with the highest autocorrelated lag amplitude for each computation type is shown in Figure 4.2.2. The AR feature is the position of the autoregressive feature position of the time step with the highest autocorrelation amplitude for the 168 previous hours that are above the specified theta threshold. The results show that both types have the same position, “y-2”, of the autoregressive feature position with the highest amplitude.

Type	Month ▲	AR Feature	50% of Time Steps	60% of Time Steps	70% of Time Steps	80% of Time Steps	90% of Time Steps
ACF	March	y-2	289	346	404	461	519
ACF	April	y-2	277	332	387	442	497
ACF	May	y-2	289	346	404	461	519
ACF	December	y-2	289	346	404	461	519
Power_Cepstrum	March	y-85	0	0	0	2	2
Power_Cepstrum	March	y-2	289	346	404	459	517
Power_Cepstrum	April	y-2	277	332	387	442	497
Power_Cepstrum	May	y-2	289	346	404	461	519
Power_Cepstrum	December	y-2	289	346	404	461	519

Figure 4.2.2 Quantity of time steps with highest autocorrelation amplitude for each type, each month and for each % of time step usage.

The analysis comparing the time steps using ConvLSTM when performing Power Cepstrum or ACF shows that not every step is the same. For example, at 50% of the time steps when using ConvLSTM for March, the results show that 67.36% of the time steps when using Power Cepstrum or ACF are the same, indicating that 32.64% of the time steps when using ConvLSTM are different when comparing the two types.

date (Year Month) ▲	50% of Lags	60% of Lags	70% of Lags	80% of Lags	90% of Lags
March	67.36%	64.24%	66.67%	76.74%	91.67%
April	65.94%	65.58%	66.67%	72.46%	82.97%
May	73.61%	80.90%	81.94%	89.58%	87.50%
December	80.21%	85.07%	83.68%	76.04%	80.90%

Figure 4.2.3 Results comparing % of same time steps that uses ConvLSTM when using Power Cepstrum or ACF.

The pattern of the difference between time steps being used in ConvLSTM when using Power Cepstrum or ACF can be identified when summarizing the quantity of time steps using ConvLSTM per hour of the day, the results in Figure 4.2.4 show that there is a pattern with higher quantity of time steps using ConvLSTM during 9 AM and 8PM for Power Cepstrum, according to Figure 4.1.3 are the moments of the day with higher global active power average. The pattern observed in Figure 4.2.5 for ACF show higher quantity of lags using ConvLSTM during afternoon, between 10AM and 6PM, the moment where there is lower global active power average.

The pattern of difference between the time steps used in ConvLSTM when using Power Cepstrum or ACF can be seen by summing the number of time steps using ConvLSTM per hour of the day. The results in Figure 4.2.4 show that there is a pattern with a higher number of time steps using ConvLSTM during 9 AM and 8 PM for Power Cepstrum, according to Figure 4.1.3, these are the moments of the day with a higher global active power average. The pattern observed in Figure 4.2.5 for ACF shows a higher number of time steps using ConvLSTM during the afternoon, between 10 AM and 6 PM, the time when the global active power average is lower.

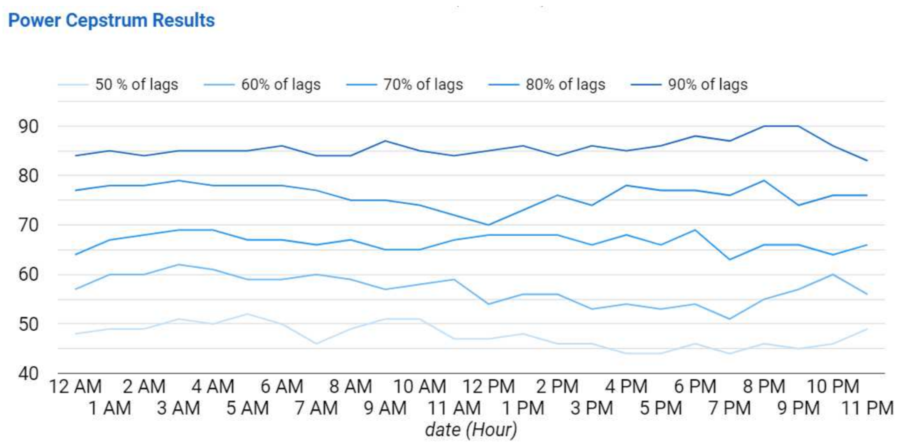

Figure 4.2.4 Sum of time steps using ConvLSTM when using Power Cepstrum for the months of March, April, May and December.

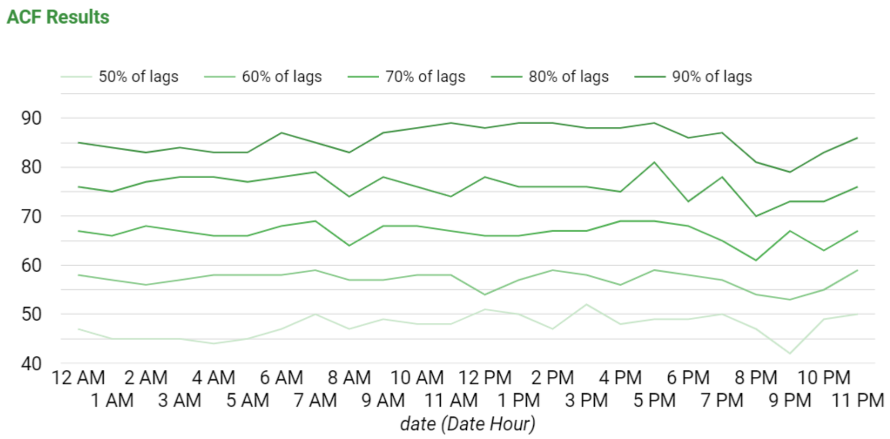

Figure 4.2.5 Sum of time steps using ConvLSTM when using ACF for the months of March, April, May and December.

The differences between Power Cepstrum and ACF can be seen in Figure 4.2.6. The figure shows the sum of time steps that are different using ConvLSTM and when using Power Cepstrum or ACF, the highest delta of the amount of time steps using ConvLSTM is between 9 AM and 5 PM with higher values for ACF and between 7 PM and 10 PM with higher values for Power Cepstrum. This shows that when ACF is used for the previous 168 hours lags for time steps between 9 AM and 5 PM, the amplitude of the highest lag is higher than the amplitude of the highest lag between 8 PM and 10 PM and the opposite reasoning for Power Cepstrum.

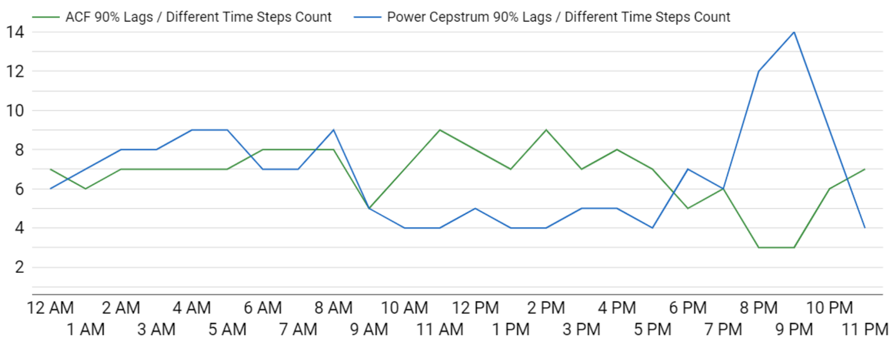

Figure 4.2.6 Quantity of different time steps using ConvLSTM when using ACF for the months of March, April, May and December when 90% of lags are using ConvLSTM.

4.3. MODELS RESULTS FOR HOUR RESOLUTION

The tests were done repeating 10 times each configuration from Benchmark models described in Table 3.4 and for each theta threshold from Figure 4.2.1, the scores are the minimum CV-Residual (%) calculated with Equation 4 and the % of Time Steps are the quantity of time steps using ConvLSTM in CLSAF model, the results show that the model with highest accuracy is the ConvLSTM model with an average of 0.5274 in columns “Grand total”, but not so far from CLSAF – ACF using (t-1) and CLSAF – Power Spectrum using (t-1) for input, the best average are 0.5313 and 0.5302 respectively for 90% of time steps using ConvLSTM, but for 60% of time steps the average are 0.5380 and 0.5397, respectively, comparing to Persistence model, with 0.5731, an improvement of 6.5% and and 1,9% lower than ConvLSTM, the positive effect is the time consumption of CLSAF model, that is lower than ConvLSTM. The scores results are similar when comparing ACF and Power Spectrum, just for 50% of time steps that ACF has a better score than Power Cepstrum, 0.5394 against 0.5459. It is noticed that December is a very good month for predictions, but with low volatility the Persistence Model performed very well with similar scores comparing to ConvLSTM and CLSAF with autoregressive lag as (t-1), for March, April and May is observed higher improvement comparing the models to the Persistence Model, for example in March with an improvement of 14%. The score results observed for CLSAF models using autoregressive lags with the highest autocorrelated lag showed bad performance compared to Persistence and other models. The results in Figure 4.3.1.

Tests were performed by repeating each configuration of the benchmark models described in Table 3.4 10 times. For each theta threshold from Figure 4.2.1, the scores are the minimum CV -Residual (%) calculated using Equation 4, and the % of time steps are the number of time steps used by ConvLSTM in the CLSAF model, the model with highest accuracy is the ConvLSTM model with an average score of 0.5274 in the "Grand total" column, but not so far from CLSAF - ACF using (t-1) and CLSAF - Power Spectrum using (t-1) for the input, the best average values are 0.5313 and 0.5302, respectively, for 90% of the time steps using ConvLSTM, but for 60% of the time steps, the average values are 0.5380 and 0.5397, respectively. Compared to the persistence model with 0.5731, an improvement of 6.5% and 1.9% lower than ConvLSTM, the positive effect is the time consumption of the CLSAF model, which is lower than ConvLSTM. The scores results are similar when comparing ACF and Power Spectrum, except that ACF performs better than Power Cepstrum at 50% of the time steps (0.5394 versus 0.5459). It is noticeable that December is a very good month for predictions, but at low volatility the persistence model performs very well, with similar results compared to ConvLSTM and CLSAF with autoregressive lag as (t-1). For March, April and May, a higher improvement is observed when comparing the models to the persistence model, for example in March with an improvement of 14%. The results for the CLSAF models using autoregressive lags as input show poor performance compared to Persistence and the other models. The results in Figure 4.3.1.

⊟ Model	% of Time Steps	March	April	May	December	**Grand total**
ConvLSTM	100.00%	0.5188	0.5291	0.5671	0.4944	**0.5274**
CLSAF - ACF (t-1)	90.00%	0.5268	0.5282	0.5747	0.4954	**0.5313**
	80.00%	0.5369	0.5280	0.5654	0.4992	**0.5324**
	70.00%	0.5337	0.5280	0.5788	0.4908	**0.5328**
	60.00%	0.5464	0.5381	0.5766	0.4909	**0.5380**
	50.00%	0.5519	0.5463	0.5786	0.4807	**0.5394**
CLSAF - Power Cepstrum (t-1)	90.00%	0.5247	0.5286	0.5608	0.5067	**0.5302**
	80.00%	0.5313	0.5319	0.5709	0.4963	**0.5326**
	70.00%	0.5495	0.5356	0.5748	0.4973	**0.5393**
	60.00%	0.5571	0.5398	0.5689	0.4930	**0.5397**
	50.00%	0.5632	0.5488	0.5755	0.4961	**0.5459**
Persistence	0.00%	0.5982	0.5907	0.6011	0.5025	**0.5731**
CLSAF - ACF (t-pn)	90.00%	0.6037	0.6191	0.6549	0.5825	**0.6151**
	80.00%	0.6064	0.6158	0.6425	0.5806	**0.6113**
	70.00%	0.6036	0.5956	0.6405	0.5699	**0.6024**
	60.00%	0.6004	0.5901	0.6336	0.5640	**0.5970**
	50.00%	0.5922	0.5904	0.6246	0.5415	**0.5872**
CLSAF - Power Spectrum (y-pn)	90.00%	0.6012	0.6333	0.6491	0.5954	**0.6197**
	80.00%	0.6005	0.6269	0.6363	0.5886	**0.6131**
	70.00%	0.5986	0.6235	0.6244	0.5739	**0.6051**
	60.00%	0.6050	0.6149	0.6275	0.5680	**0.6039**
	50.00%	0.5991	0.6072	0.6207	0.5664	**0.5984**

Figure 4.3.1 Model CV-Residual score results for hour resolution on March, May, April and December of 2019, by % of time steps using ConvLSTM.

The main advantage of the CLSAF model is the lower runtime consumption, with a difference of 7 seconds to execute the prediction, while maintaining model accuracy. This difference can be very significant for longer lengths, as we will see in the test with 30 minutes and 1 minute resolution. The results for the maximum loss in calculating the difference between electricity consumption prediction and the observed consumption show a better performance of the CLSAF models compared to ConvLSTM. The results in Figure 4.3.2.

Model	% of Time Steps	Time (seconds)	Max Loss
CLSAF - Power Cepstrum (t-1)	90.00%	45.32	2.41
	80.00%	43.62	2.39
	70.00%	42.21	2.36
	60.00%	39.69	2.76
	50.00%	37.62	2.71
CLSAF - ACF (t-1)	90.00%	42.25	2.61
	80.00%	41.84	2.27
	70.00%	41.39	2.34
	60.00%	39.92	2.34
	50.00%	38.00	2.44
ConvLSTM	100.00%	45.46	2.59

Figure 4.3.2 Time in seconds to run prediction by model and % of time steps using ConvLSTM for March, April, May and December of 2019.

The CLSAF-Power Cepstrum (y-1) and CLSAF-ACF (y-1) models with theta threshold for 70% of the time steps using ConvLSTM, from 13-04-2019 to 25-04-2019, were shown in Figure 4.3.3 and Figure 4.3.4with detailed information about the time steps using Persistence or ConvLSTM. The yellow dashed line indicates the theta threshold. When the highest value of the autocorrelation amplitude in the yellow line is below the theta threshold, the models use the Persistence model; in the red line, when the amplitude is higher, the models use the ConvLSTM model; in the green line for ACF; and in the blue line for Power Cepstrum.

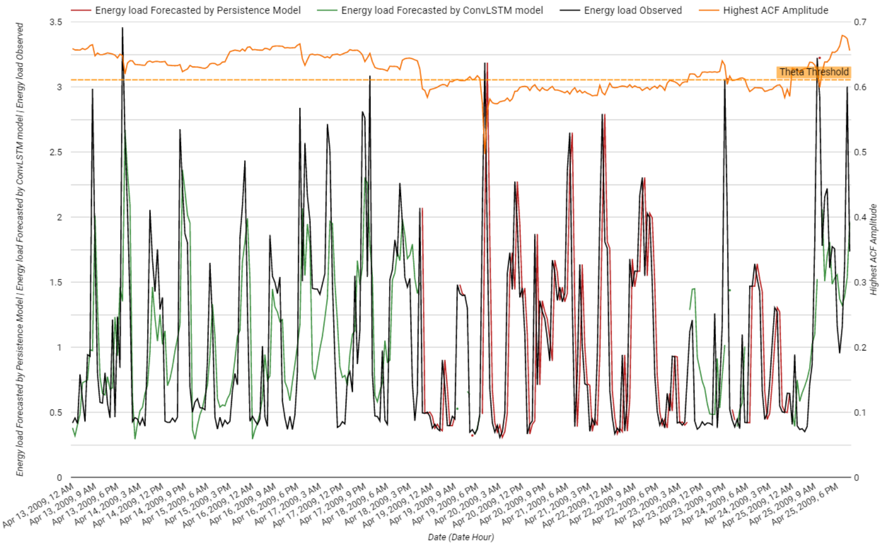

Figure 4.3.3 CLSAF – ACF (y-1) model prediction results from 13-04-2019 to 25-04-2019, with 70% of time step using ConvLSTM which is theta threshold of 0,610852283363079 and 160 hours of warm-up.

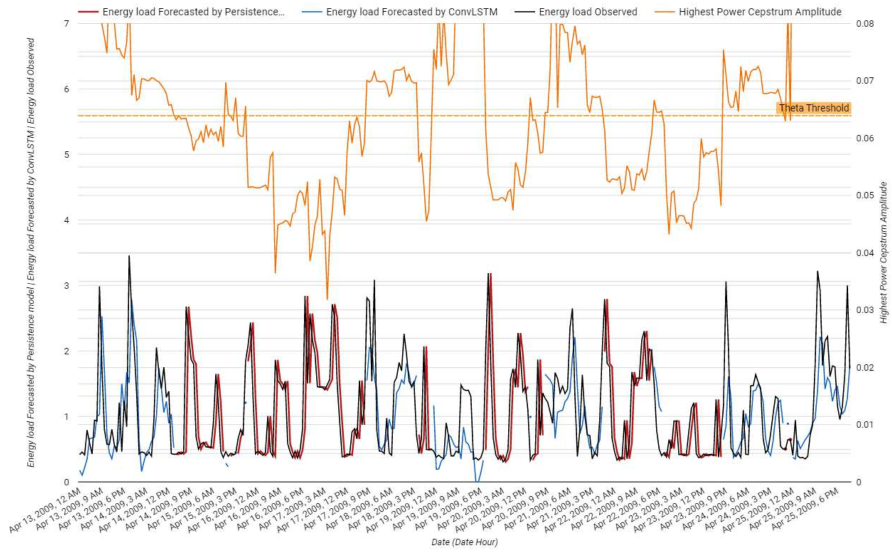

Figure 4.3.4 CLSAF – Power Cepstrum (y-1) model prediction results from 13-04-2019 to 25-04-2019 with 70% of time step using ConvLSTM which is theta threshold of 0,0639021864467233 and 160 hours of warm-up.

4.4. RESULTS FOR HIGHER RESOLUTION

Following the tests for hour resolution, the first step for higher resolution was to identify the theta threshold for each % of lag usage, for this analysis will be used the month of April in 2019 only.

		Resolution / Theta Threshold	
Type	% of lag usage	1 Minute	30 Minute
Power_Cepstrum	90.00%	0.137822	0.072104
	80.00%	0.178384	0.080827
	70.00%	0.199799	0.087012
	60.00%	0.216199	0.092681
	50.00%	0.234025	0.098915
ACF	90.00%	0.835712	0.657827
	80.00%	0.866142	0.669192
	70.00%	0.886346	0.689335
	60.00%	0.903944	0.702136
	50.00%	0.917894	0.713100

Figure 4.4.1 Theta threshold values for one minute and 30 minutes resolution for Power Cepstrum and ACF and for each % of time steps using ConvLSTM in April 2019.

At 30 minute resolution, the results show great performance of the CLSAF models compared to Persistence and ConvLSTM, with a CLSAF Power Cepstrum (y-1) of 0.5182 from CV -Residual(%) using 90% of the time steps with ConvLSTM, 6.3% better than the Persistence model and 1.59% than ConvLSTM and the performance for other % of the time steps remains acceptable considering that the time to run is lower when using lower % of Time steps as we can see in Figure 4.4.3. At 1 minute resolution, the results show that the models are worse than the Persistence model and are not usable. The results in Figure 4.4.2.

		Resolution / score	
Model	% of Time steps	1 Minute	30 Minutes
CLSAF - Power Cepstrum (y-1)	90.00%	0.2307	0.5182
	80.00%	0.2293	0.5234
	70.00%	0.2270	0.5277
	60.00%	0.2254	0.5304
	50.00%	0.2252	0.5401
Persistence	0.00%	0.2252	0.5534
CLSAF - ACF (y-1)	90.00%	0.2317	0.5242
	80.00%	0.2317	0.5228
	70.00%	0.2308	0.5251
	60.00%	0.2294	0.5272
	50.00%	0.2306	0.5330
ConvLSTM	100.00%	0.2379	0.5266

Figure 4.4.2 Model CV-Residual score results for minute and 30 minute resolution on April of 2019, by % of time steps using ConvLSTM.

Results for run time and maximum loss are shown only for the 30-minute resolution because the persistence model was the best model for the 1-minute resolution. As expected, the time difference between the ConvLSTM and CLSAF models in running the prediction is larger at longer lengths, with an improvement of about 40% compared to 50% of the time steps. It can be observed that CLSAF when using Power Cepstrum is 11% faster compared to ACF.

Model	% of Time Steps	Time (seconds)	Max Loss
ConvLSTM	100.00%	124.34	3.82
CLSAF - Power Cepstrum (y-1)	90.00%	88.99	3.76
	80.00%	84.67	3.78
	70.00%	79.56	3.78
	60.00%	77.59	3.74
	50.00%	73.23	3.75
CLSAF - ACF (y-1)	90.00%	95.50	3.76
	80.00%	92.20	3.74
	70.00%	87.44	3.75
	60.00%	85.26	3.76
	50.00%	82.15	3.73

Figure 4.4.3 Time in seconds for 30-minute resolution to run prediction by model, % of time steps using ConvLSTM for April of 2019.

4.5. RESULTS FOR DIFFERENT INPUTS

The results for higher inputs were run using the same theta threshold as in Figure 4.2.1, since the highest autocorrelated amplitude for the hourly resolution remains the same. The month chosen for testing is the same as for the higher resolution, April 2019. As mentioned in the methodology, the ConvLSTM configuration was changed for higher inputs, with higher epochs in the warm-up phase, as shown in **Appendix 5**, with better results observed at 50 epochs. Tests were performed for input lengths of 1, 2, 3, 4, 5, 6, 12, and 24. The results show that the score improves with higher input lengths. The best average score was observed for a 6-step input, 0.89% better than a single step input. The best score, 0.5118 CV -Residual, was obtained from CLSAF Power Cepstrum with 80% of lags using the ConvLSTM model. Detailed results in Figure 4.5.1.

		Input Length / score							
Model	% of Time steps	1	2	3	4	5	6	12	24
Persistence	0.00%	0.5907	0.5907	0.5907	0.5907	0.5907	0.5907	0.5907	0.5907
CLSAF-ACF	90.00%	0.5263	0.5252	0.5374	0.5276	0.5228	0.5197	0.5414	0.5445
	80.00%	0.5186	0.5213	0.5207	0.5264	0.5203	0.5206	0.5191	0.5658
	70.00%	0.5222	0.5263	0.5244	0.5236	0.5351	0.5258	0.5291	0.5906
	60.00%	0.5348	0.5447	0.5422	0.5473	0.5345	0.5396	0.5339	0.5432
	50.00%	0.5381	0.5455	0.5474	0.5466	0.5436	0.5418	0.5501	0.5445
ConvLSTM	100.00%	0.5215	0.5237	0.5249	0.5222	0.5205	0.5186	0.5171	0.5832
CLSAF-Power Cepstrum	90.00%	0.5215	0.5207	0.5180	0.5213	0.5245	0.5163	0.5240	0.5826
	80.00%	0.5264	0.5219	0.5304	0.5218	0.5209	0.5118	0.5249	0.5615
	70.00%	0.5307	0.5289	0.5281	0.5296	0.5183	0.5184	0.5162	0.5761
	60.00%	0.5358	0.5388	0.5364	0.5356	0.5391	0.5264	0.5393	0.5579
	50.00%	0.5477	0.5554	0.5456	0.5502	0.5449	0.5326	0.5382	0.5495

Figure 4.5.1 Model CV-Residual score results for hour resolution on different input length, in April of 2019, by % of time steps using ConvLSTM.

The runtime results show that the runtime is similar at higher length and lower at lower % of time steps with ConvLSTM. Results shown in Figure 4.5.2.

		Input Length / Time (seconds)							
Model	% of Time Steps	1	2	3	4	5	6	12	24
ConvLSTM	100.00%	53.40	51.71	51.35	51.26	51.28	50.71	51.88	51.44
CLSAF-Power Cepstrum	90.00%	50.39	50.04	50.08	50.15	50.02	49.46	50.16	50.73
	80.00%	48.59	48.20	48.84	48.21	47.93	47.88	48.53	48.89
	70.00%	46.42	45.85	45.94	46.39	45.74	46.32	46.00	47.04
	60.00%	44.54	44.61	43.98	43.43	43.73	43.91	44.95	45.02
	50.00%	43.09	42.34	42.30	42.24	42.44	41.96	42.51	43.05
CLSAF-ACF	90.00%	48.75	47.88	48.86	49.23	48.42	47.93	48.32	48.63
	80.00%	44.25	46.35	46.93	47.18	46.22	46.23	46.53	47.24
	70.00%	44.64	45.14	44.66	45.20	44.98	44.31	44.76	45.17
	60.00%	43.28	42.90	43.06	43.08	42.59	43.32	43.06	42.97
	50.00%	41.49	41.03	41.08	40.87	40.77	41.13	41.39	40.65

Figure 4.5.2 Time in seconds to run prediction for each length by model and % of time steps using ConvLSTM for April of 2019.

5. CONCLUSIONS

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6. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORKS

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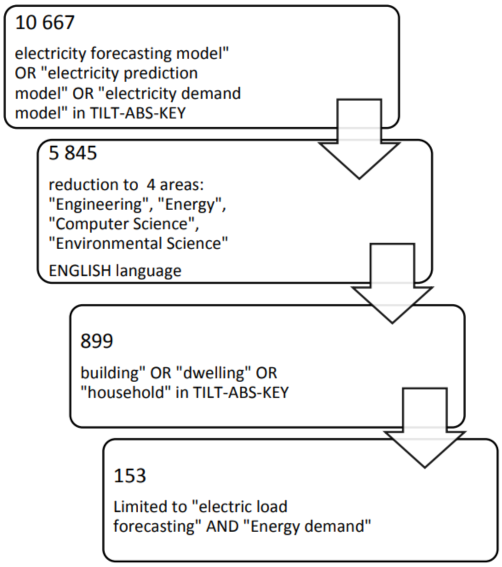
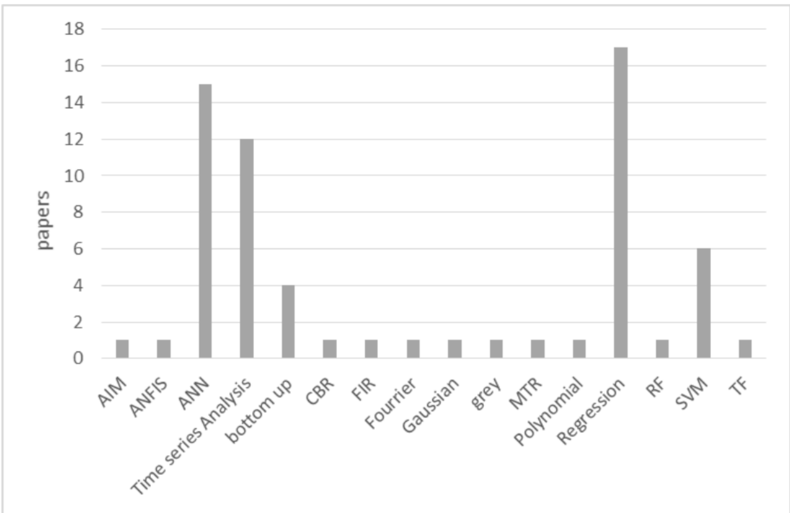
7. BIBLIOGRAPHY

8. APPENDIX (OPTIONAL)

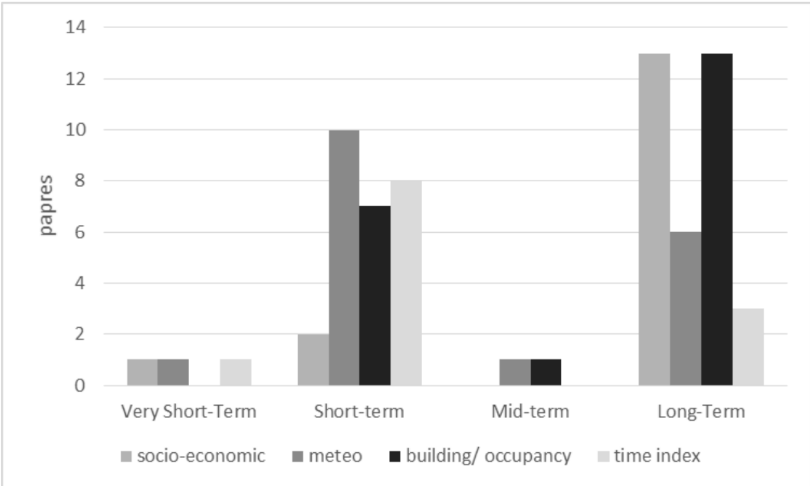
Appendix 1 *- Selection procedure presented. Source:* (Kuster et al., 2017).



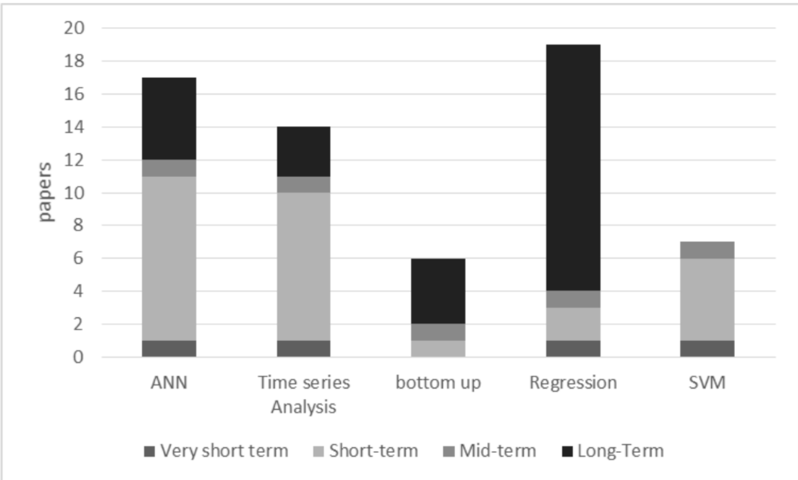
Appendix 2 - Classified forecasting models distribution. Source: (Kuster et al., 2017).



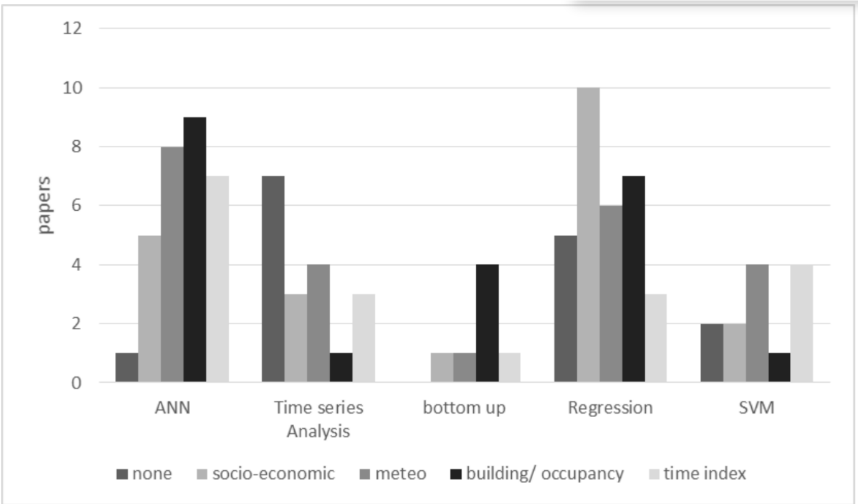
Appendix 3 - Input distribution depending on the scale. Source: (Kuster et al., 2017).



Appendix 4 - Model vs time horizon distribution. Source : (Kuster et al., 2017).



Appendix 5 - Model vs inputs distribution. Source: (Kuster et al., 2017).



Appendix 5 - *The ConvLSTM structure and parameters.*

Property	**Value**
Structure	One ConvLSTM2D layer and two dense layers
Filters	36
Kernel Size	(1,2)
Activation function	Relu
Nodes number of the first dense layer	4
Nodes number of the second dense layer	1
Epoch	20
Epochs testing Higher inputs	50
Batch size	1
Loss function	MSE
Optimizer	Adam
Epochs retraining	1
Input shape (steps, length, features)	(1,1,n)
Output shape (length, features)	(1,1)

9. ANNEXES (OPTIONAL)