Creating Standard Load Profiles in Residential and Commercial Sectors in Germany for 2016, 2025 and 2040

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Abstract. Standard load profiles (SLPs) are used to calculate the natural gas demand of non-daily metered customers based on temperature forecasts. The most recent version of natural gas SLPs in Germany was published by the Federal Association of Energy and Water in June 2015. With the concept SigLinDE, a linearization of the old SLPs was carried out mainly for adjusting the SLP values in low temperatures as well as high temperatures. Therefore, an additional water heating line and a space heating line were introduced. These SLPs are based on historic data and represent the actual situation. But they are not helpful for the calculation of daily gas demand of SLP customers in Germany in long-term. Better insulation of buildings or more efficient heating systems will change the SLPs in the future. Thus, the concept of the SigLinDE profiles is used in this paper to create SLPs till 2040. For this purpose, a LP model was developed in GAMS environment. The model is executed for one- and two-family dwellings, apartments and the commercial sector for the years 2016, 2025 and 2040. The obtained SLPs demonstrate that year by year, the heating phase will be started at colder temperatures most probably due to the technology improvements.

Keywords: standard load profile, SLP, residential sector, commercial sector, GAMS, LP

1   Introduction

Standard load profiles (SLPs) are used to forecast the daily consumption of natural gas by small customers. In general, there are two categories of natural gas consumers: non-daily metered consumers (or SLP customers) and real-time metered customers (or RLM customers). SLP customer is referred to customers with an annual consumption of less than 1,500 MWh and an installed power of less than 500 kW per hour.

SLPs have been continuously revised and updated in order to match to the current situations and provide a better forecast. A summary of the revisions

made to the SLPs can be found in [5]. In June 2015, the most recent revision of
SLPs was published by Federal Association of Energy and Water (in German:
Bundesverband der Energie- und Wasserwirtschaft e.V.; BDEW) in cooperation
with VKU and the European Association of Business and Distribution Organi-
zations for Energy (GEODE). From 1st October 2015, all network operators can
use the new profiles [1]. In the recent revision, the so called SigLinDE profiles
were introduced. These profiles are composed of a sigmoid term and a linear
term. The aim for adding the linear term was to adjust the profiles for the cold
temperatures and review the profiles at the high temperatures.

Stadtwerke München GmbH operate a worldwide gas market model to ana-
lyze gas prices and trade flows till 2040 [2], [3], [4]. An input parameter is the
gas demand of each day from 2016 to 2040. Actual SLPs were generated, based
on historic data. But in the future buildings will be better insulated, heating
systems will be more efficient and there will be changes in family structures and
in floor space per person. Therefore, actual SLPs are not helpful to calculate the
daily demand of SLP customers in long-term and no research was made so far to
generate SLPs for the future. Thus, new SLPs are created in this paper for one-
and two-family dwellings (EFH), apartments (MFH) and the commercial sector
(GHD) for the years 2016, 2025 and 2040. For this purpose, the linearization
concept SigLinDE is used in a LP model in GAMS environment.

The outline of this study is as follows: in section 2, the souce code of the
GAMS model is explained. Subsequently, the generated SLPs are presented in
section 3. In section 4, the outcomes of this paper are enumerated and a conclu-
sion is made.

2 The GAMS Sorce Code of the SLP Generating Model

In order to create SLPs for future years, the SigLinDE profile should be updated.
This update can be done in two ways; either by simultaneous modification of
both sigmoid and linear terms or by modification of either of sigmoid or linear
term. However, the modification of the sigmoid term is not desirable because:

– The modification of the sigmoid term adds non-linearity to the problem and
  makes the problem solving procedure highly time consuming.
– Achieving a global optimum solution of the problem requires further as-
  sumptions that increase the size and complexity of the problem as well as
  uncertainty about the results.

The SLP generating model is implemented in GAMS environment. In the
next lines, the sets and parameters are defined. The parameters are transferred
from the input Excel file to a GDX file which can be read by GAMS. Subse-
quently, the values are assigned to their corresponding sets or parameters. Some
sets are proliferated in order to use them as counters within the loops and iter-
ations and also in the model in order to keep it smaller.

```
001 Sets
002   Y
003   Day
004   HSize
005 Parameters
006   Sig(Day,HSize,Y)
007   T(Day,Y)
008   KW(HSize,Y)
009   Dem(HSize,Y)
010   a(Day)
011   b(Day)
012   DF(Day,HSize)
013
014 $CALL GDXXRW.EXE  i=M:\IOExcel.xlsx o=M:\IOExcel.gdx index=index!
015 $GDXIN M:\SLP_Tool_V4\IOExcel.gdx
016 $load Y
017 $load Day
018 $load HSize
019 $load Sig
020 $load T
021 $load KW
022 $load Dem
023 $GDXIN;
024 $load DF
025
026 Scalars
027   CountY
028   CountHSize;
029
030 alias(Day,D,DD);
031 alias(Y,Annum);
032 alias(HSize,HS);
```

The variables take values during the execution procedure in order to satisfy the aim of the optimization process. Normally, the solvers assign a starting value of zero to the variables. Therefore, equations which can be lead to division by zero should be avoided by adding *eps* to the variables where it is appropriate.

```
033 Variables
034   jH(Day,HSize,Y)
035   jW(Day,HSize,Y)
036   Obj
037 Positive Variables
038   bH(HSize,Y)
039   bW(HSize,Y)
040   z(Day,HSize,Y)
041   Dev(HSize,Y)
042 Negative Variables
043   mH(HSize,Y)
044   mW(HSize,Y);
```

In order to attain results in a feasible span, some variables are bounded. The boundary values are determined based on the nature of the space heating line and water heating line around the values given by SigLinDE profile. It should be noted that that these boundaries are wide enough to make sure that the obtained results are meaningful.

```
045 *9 < T < 19
046 mH.lo('EFH',Y)= -0.063155224137931;
047 mH.up('EFH',Y)= -0.046961576923077;
048 bH.lo('EFH',Y)=  0.568397017241379;
049 bH.up('EFH',Y)=  0.892269961538461;
050 mH.lo('MFH',Y)= -0.054684827586207;
051 mH.up('MFH',Y)= -0.040663076923077;
052 bH.lo('MFH',Y)=  0.492163448275862;
053 bH.up('MFH',Y)=  0.772598461538462;
054 mH.lo('GHD',Y)= -0.060725003448276;
055 mH.up('GHD',Y)= -0.04515448974359;
056 bH.lo('GHD',Y)=  0.546525031034483;
057 bH.up('GHD',Y)=  0.857935305128205;
058 mW.up(HSize,Y)$(ord(HSize) eq 1 or ord(HSize) eq 2)=
        -0.00139626430895863;
059 mW.lo(HSize,Y)$(ord(HSize) eq 1 or ord(HSize) eq 2)=
        -0.00244346581569938;
060 mW.up(HSize,Y)$(ord(HSize) eq 3)= -0.00086;
061 mW.lo(HSize,Y)$(ord(HSize) eq 3)= -0.0012;
```

The following equations determine the relation between the variables. In other words, the variables are obliged to obey these equations. Equations determine the space of the problem.

```
062 Equations
063   HeatLine(Day,HSize,Y)
064   WaterLine(Day,HSize,Y)
065   HeatLineEFH(HSize,Y)
066   HeatLineMFH(HSize,Y)
067   HeatLineGHD(HSize,Y)
068   WaterLineEFH(HSize,Y)
069   WaterLineMFH(HSize,Y)
070   WaterLineGHD(HSize,Y)
071   CondA(Day,HSize,Y)
072   CondB(Day,HSize,Y)
073   CondC(Day,HSize,Y)
074   Constraint(HSize,Y)
075   Objective;
```

In Germany, within the high temperatures ($>24°C$), it is assumed that gas in residential and commercial sectors is purely consumed for water heating and cooking purposes. Mean daily temperatures of above $28°C$ scarcely occur in Germany. Also, extremely cold days (mean daily temperatures of below -20°C) are seldom experienced [5]. Therefore, it is assumed that the h-value does not

change at these temperatures and the heating systems work at full load. These
assumptions are translated to the following constraints in the model:

- Fixed amplitude at -20°C for the space heating line for any year in the future.
- Fixed intersection point with the temperature axis for the water heating line
  in any year in the future.

```
076 HeatLine(Day,HSize,Y)$(ord(HSize) eq CountHSize and ord(Y) eq
        CountY).. jH(Day,HSize,Y)=e=mH(HSize,Y)*T(Day,Y)+bH(HSize,Y);
077 WaterLine(Day,HSize,Y)$(ord(HSize) eq CountHSize and ord(Y) eq
        CountY).. jW(Day,HSize,Y)=e=mW(HSize,Y)*T(Day,Y)+bW(HSize,Y);
078 HeatLineEFH(HSize,Y)$(ord(HSize) eq 1).. mH(HSize,Y)*(-20)+
        bH(HSize,Y)=e=1.8315015;
079 HeatLineMFH(HSize,Y)$(ord(HSize) eq 2).. mH(HSize,Y)*(-20)+
        bH(HSize,Y)=e=1.58586;
080 HeatLineGHD(HSize,Y)$(ord(HSize) eq 3).. mH(HSize,Y)*(-20)+
        bH(HSize,Y)=e=1.7610251;
081 WaterLineEFH(HSize,Y)$(ord(HSize) eq 1).. (eps+mW(HSize,Y))*
        48.6404708012675+bW(HSize,Y)=e=eps;
082 WaterLineMFH(HSize,Y)$(ord(HSize) eq 2).. (eps+mW(HSize,Y))*
        53.7279121863799+bW(HSize,Y)=e=eps;
083 WaterLineGHD(HSize,Y)$(ord(HSize) eq 3).. (eps+mW(HSize,Y))*
        124.996887086124+bW(HSize,Y)=e=eps;
```

The variables a and b are set so that always one of them is set to one and
the other is set to zero. Using these variables, the variable z is located on either
space or water heating line. Conditions A and B makes sure that the variable
z has a value greater or equal to the amplitude of both space and water heat-
ing lines. With this method, the discrete problem which causes non-linearity is
transformed to a linear problem. This increases highly the speed of convergence
and runtime of the model.

```
084 CondA(Day,HSize,Y)$(ord(HSize) eq CountHSize and ord(Y) eq CountY)..
        z(Day,HSize,Y)=g=jH(Day,HSize,Y);
085 CondB(Day,HSize,Y)$(ord(HSize) eq CountHSize and ord(Y) eq CountY)..
        z(Day,HSize,Y)=g=jW(Day,HSize,Y);
086 CondC(Day,HSize,Y)$(ord(HSize) eq CountHSize and ord(Y) eq CountY)..
        z(Day,HSize,Y)=e=a(Day)*jH(Day,HSize,Y)+ b(Day)*jW(Day,HSize,Y);
```

A lower bound of zero for the difference of the given annual demand and the
sum of the daily demands is defined. This difference is defined as an objective
function. In other words, this deviation should be minimized by the optimization
process. Subsequently, the above sets, parameters, variables and equations are
defined as SLPGenTool.

```
087 Constraint(HSize,Y)$(ord(HSize) eq CountHSize and ord(Y) eq CountY)..
        Dev(HSize,Y) =e= Dem(HSize,Y) - KW(HSize,Y) * (sum(Day,
        DF(Day,HSize)*(z(Day,HSize,Y) + Sig(Day,HSize,Y))));
088
089 Objective.. Obj=e=sum((HSize,Y)$(ord(HSize) eq CountHSize and ord(Y)
        eq CountY),Dev(HSize,Y));
090 Model SLPGenTool /all/;
```

Within the loops, different configurations for a and b are set so that always $a + b = 1$ for $a, b \in 0, 1$. Both a and b have 365 elements and are input to the model. The model is solved in a loop in which firstly, all the elements of a are zero and all the elements of b are one i.e. it is assumed that all elements are on the space heating lines and with the given temperature profile, space heating line always has a higher amplitude compared to the water heating line. If the model was feasible and the objective value was enhanced, the model outputs are saved as the global solution and the next loop is started. In the case of infeasibility, nothing is saved and the program starts the next loop. In the next loop, all the elements of a except the one corresponding to the highest existing temperature remain zero and the last element becomes one. The elements of b are changed accordingly. This loop means that except for one temperature, in all other cases, the space heating line has a higher amplitude compared to the water heating line. Again, in case of improvement in the objective value, the results are replaced with the previous values. This process is continued until the improvement of the objective value stops. There, the program quits from the loop and stores the global optimum value as well as model outputs in the memory. The process is done for all categories (one- and two-family dwellings, apartments and commercial sector) and for all the years in the forecasting horizon. Afterwards, the properties of the global solution are transferred to the GDX file and then, to the output Excel file.

```
091 set LData optimum line data / obj
092                                 mHL
093                                 bHL
094                                 mWL
095                                 bWL
096                                 BestEl/
097 Parameter
098   c
099   GlobalSol(LData,HSize,Y);
100   GlobalSol("BestEl",HS,Annum)=0;
101   GlobalSol("Obj",HSize,Y)=50000;
102
103 loop((Annum,HS),
104   CountY=ord(Annum);
105   CountHSize=ord(HS);
106   loop(D,
107     c=365-ord(D);
108       loop(DD,
109         if( ord(DD) le c+1,
110           a(DD)=1;
111           b(DD)=0;
112         else
113           a(DD)=0;
114           b(DD)=1;
115         );
116       );
117     Solve SLPGenTool using lp minimizing Obj;
118
```
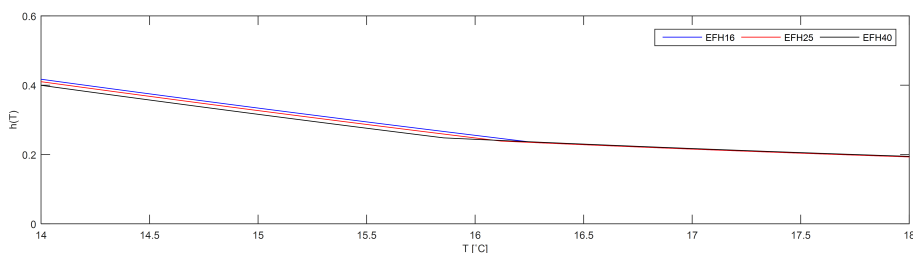
```
119      if((SLPGenTool.modelstat eq 1) and (Obj.l <
            GlobalSol("Obj",HS,Annum)),
120      GlobalSol("Obj",HS,Annum)=Obj.l + eps;
121      GlobalSol("mHL",HS,Annum)=mH.l(HS,Annum);
122      GlobalSol("bHL",HS,Annum)=bH.l(HS,Annum);
123      GlobalSol("mWL",HS,Annum)=mW.l(HS,Annum);
124      GlobalSol("bWL",HS,Annum)=bW.l(HS,Annum);
125      GlobalSol("BestEl",HS,Annum)=ord(D);
126    );
127  );
128 );
129
130 execute_unload 'Output.gdx',GlobalSol;
131 execute 'gdxxrw.exe i=Output.gdx o=M:\Residential.xlsx index=index2
```
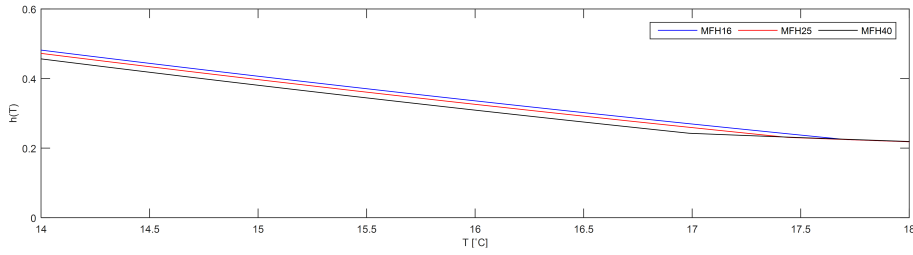
3   Model Outputs and SLPs

In this section, the SLPs for one- and two-family dwellings, apartments and the
commercial sectors for the years 2016, 2025 and 2040 presented. It can be seen
in Fig. 1, Fig. 2 and Fig. 3, as time passes, the h-value for a given temperature
decreases. Also year by year, the heating phase (where the space heating line
intersects with the water heating line) in all categories starts at colder temper-
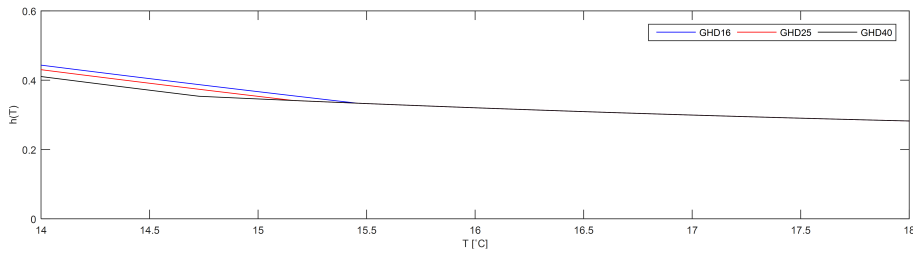atures. This can be due to the technology improvements in future.

Fig. 1. Generated SLPs of one- and two-family dwellings in 2016, 2025, 2040.

4   Conclusion

In this paper, the concept of the SigLinDE profile was used to create the future
standard load profiles. For this purpose, a model in GAMS environment was
developed. In the model, the sigmoid term of the SigLinDE profile was kept
unchanged and the slopes and the intercepts of the space heating line and the
water heating line were optimized so that the difference of the given annual
demand and summation of the daily demands is minimized. Also, an approach for

Fig. 2. Generated SLPs of apartments in 2016, 2025, 2040.

Fig. 3. Generated SLPs of commercial sector in 2016, 2025, 2040.

the linearization of the *max* term in the definition of SigLinDE profile (equation 1) was introduced.

The model was executed for one- and two-family dwellings, apartments and the commercial sectors for the years 2016, 2025 and 2040. The obtained SLPs demonstrated that year by year, the heating phase will start at colder temperatures. In other words, people will tend to start heating the buildings in colder temperatures in future most probably due to the technology improvements.

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