ENERGY SUPPLY WITH MICRO CHP FOR A RESIDENTIAL UNIT WITH ELECTRIC VEHICLE

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ABSTRACT

In the frame of a research project, the energy production for a residential unit including its mobility by micro-CHP was simulated in detail. Several variations of energetic building standards, of types of energy generation and of energy carriers were investigated. They were compared to reference scenarios in respect of primary energy consumption and environmental impact. For the building use, standard data published in Swiss standards were used. For the mobility, profiles had to be generated based on statistical census data.

The results show that micro-CHP systems are coequal to the “progressive” scenario based on a heat pump and an electric vehicle in respect of primary energy consumption. Regarding greenhouse gas emissions, they are considerably better than the “conservative” scenario based on a gas boiler and a gasoline vehicle, but not quite as good as the “progressive” scenario. Micro CHP complement ideally PV in the seasonal distribution, and with an adequate control strategy they can increase massively the consumption on site of the generated electrical energy and therefore decrease the grid load.

INTRODUCTION

In the frame of a research project funded by the Swiss Federal Office of Energy (final report: Gaegauf et al., 2012), the goal was to investigate the energy supply of a residential unit including the associated individual mobility by a micro combined heat and power (CHP) system.

For this purpose, a residential unit was simulated in detail, together with its mobility, i.e. the average energy consumption for the operation of automobiles to be associated with this unit, with different types of micro CHP units. The program IDA-ICE (Equa, 2011) was used for this purpose.

For the evaluation of the results, two reference scenarios were defined. The quantities which were compared were the primary energy consumption, the greenhouse gas emissions and eco-points according to the Swiss Federal Office of the Environment (BAFU, 2009). The latter is not presented here, since it is primarily of national interest.

The seasonal and diurnal distribution of the demand and the generation of electric energy, and in connection to this the possibility of controlling it, is of big interest in respect of the grid loads. Therefore such aspects were investigated and first results derived.

MODELLING

CHP Units

Three types of micro CHP appliances were modelled (table 1).

Table 1 Properties of the CHP units

CHP TYPE	η_{ELEC}	η_{THERM}	FUEL
Internal combustion engine (ICE)	27%	66%	Natural gas / biogas
Stirling engine	15.4%	68.6	Natural gas / wood pellets
Micro gas turbine (MGT)	24%	72%	Natural gas / biogas

The models of the CPH units are partly based on the work from IEA Annex 42 (Beausoleil-Morrison, 2008). For the micro gas turbine type, one of the project partners developed a model on the basis of laboratory measurements (Figure 1, see also Keller et al., 2011).

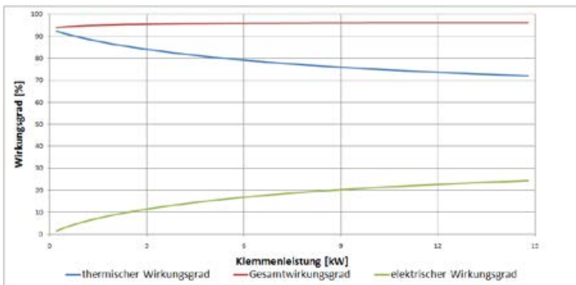

Figure 1 Electric, thermal and total efficiency functions for the MGT model for conditions with domestic hot water production, i.e. 60/20°C

Residential Unit

A single family dwelling with a floor area of 160 m^2 (figure 2) which had been used in several other studies, was chosen as the representative living unit. To enhance its representativity for the Swiss market, the use data were adapted to those of a multi-family unit according to the current Swiss standard (SIA 2024, 2006).

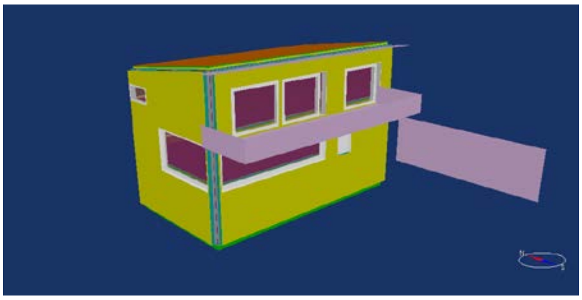

Figure 2 3D visualization of the residential unit

To cover different energetic standards, the unit was varied in three different versions:

- 'Bestand 1980': Residential unit according to the average of the years 1925 – 1965, taking into account retrofits bringing it to the stage of 1980.
- 'MuKEn': Residential unit according to the current energy regulations of the Swiss cantons (MuKEn, EnDK, 2008).
- 'Minergie-P': residential unit according to the conditions of the Swiss volontary label Minergie-P (Ragonesi et. al., 2008).

Mobility

Starting from the micro census data from the Swiss Federal Office of Statistics (Bundesamt für Statistik, 2005), a weekly profile was derived for the charging of an electric vehicle. The statistical data were differentiated for intended purpose (figures 3 and 4).

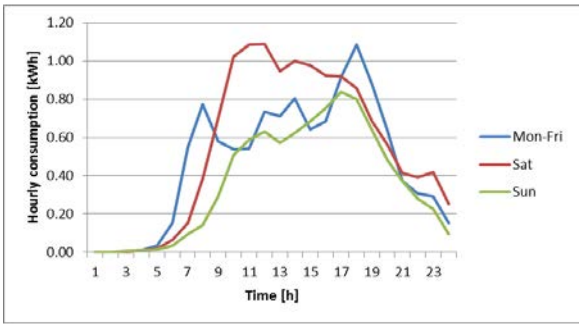

Figure 3 Statistical daily profiles for the vehicle use over all purposes of use

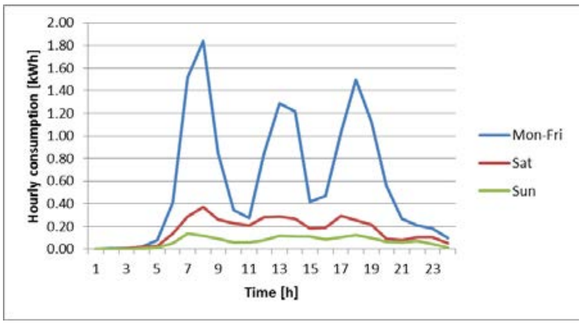

Figure 4 Statistical daily profiles for the vehicle use for the purpose of use 'work'

In order to derive a profile useable for the simulation, the statistical data were modified as follows:

- Splitting of the vehicle driving distance or the hourly energy use, respectively, according to figure 3, on two vehicles, one of them being used for the purpose of se 'work', the other one for the remaining purposes.
- Coarsening of the profiles by rounding of the values.

The profiles derived this way are shown in figure 5. This way, time slots of still stand of the vehicle arise, where the vehicle can be connected to the grid for charging.

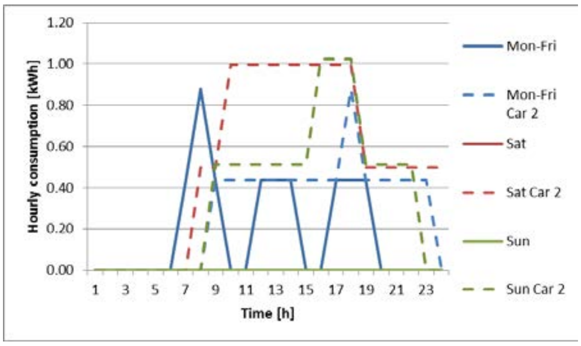

Figure 5 Profiles of the vehicle use modified for the simulation

The assumption that the vehicles are connected to the grid at the beginning of every time slot of still stand and that the energy used during the preceding driving period is recharged, leads to the vehicle charging profiles shown in figure 6.

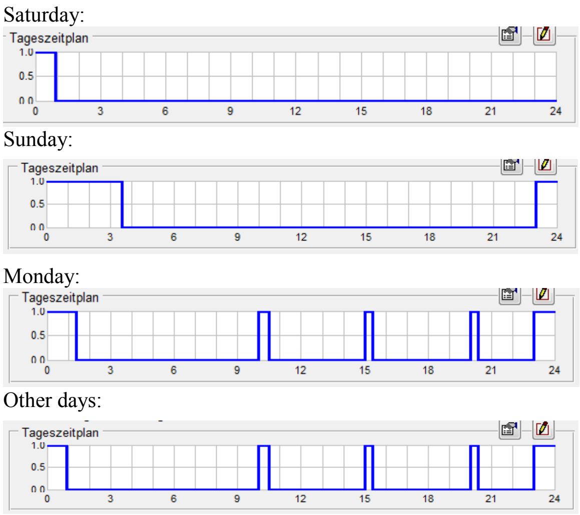

Figure 6 Vehicle charging profiles used for the simulation

For the charging profiles according to figure 6 it was assumed that charging occurs through a normal household plug protected by a 16 A fuse, leading to a charging power of 3.68 kW. The basic driving distances and use data are given in table 2.

Also, it was assumed that the vehicle is connected to the grid also during the still stand periods through daytime. It has to be mentioned that the respective charging energy is, at least for the purpose of use ‘work’, not consumed at the location of the simulated residential unit. But basically the charging time slots are concentrated on the late evening and night hours.

Whole System

The whole system with residential unit, energy supply and the use profile for the vehicle charging was set up in the simulation program IDA-ICE. The systems vary slightly depending on the energetic standard. For the micro gas turbine, due to its large power of 44 kW, the building load had to be scaled by a factor of 2, 5 or 10, depending on the energetic standard. Figure 7 shows the graphic representation of energy supply model for one variant. The model includes the heating storage tank, the DHW storage tank with a separate HP, the CHP with the charging control, the heating distribution control, the DHW consumption, the PV production and the electric vehicle consumption.

SCENARIOS

The residential unit with the CHP energy supply were compared in respect of primary energy consumption and greenhouse gas emissions with two reference scenarios:

Reference Scenario 'Conservative':

- Gas boiler for room heating and DHW generation
- Combustion engine vehicle with fossile fuel
- Grid electricity

Reference Scenario 'Progressive':

- Ground coupled heat pump for room heating and DHW generation
- Electric vehicle
- Variant: grid electricity
- Variant: grid electricity coupled with a PV plant

Scenario 'Polyvalent energy system':

- CHP unit for room heating and DHW generation
- Heat pump for DHW generation
- Electric vehicle
- Grid electricity coupled with a PV plant

These scenarios were combined with the three energetic standards for the residential unit.

Table 2 Assumptions for the derivation of the energy demand of the electric vehicle

DRIVING DISTANCE	NUMBER OF PERSONS	VEHICLE-OCCU-PATION	DISTANCE PER HOU-SEHOLD	ENERGY DEMAND SPEC. CONSUMPTION: 23 KWH/100 KM		
km/(d·p)	p/household	p/vehicle	km/(veh·a)	kWh/ (a·household)	kWh/ (W·household)	kWh/ (d· household)
25.5	3	1.57	17'785	4'090	78.4	11.2

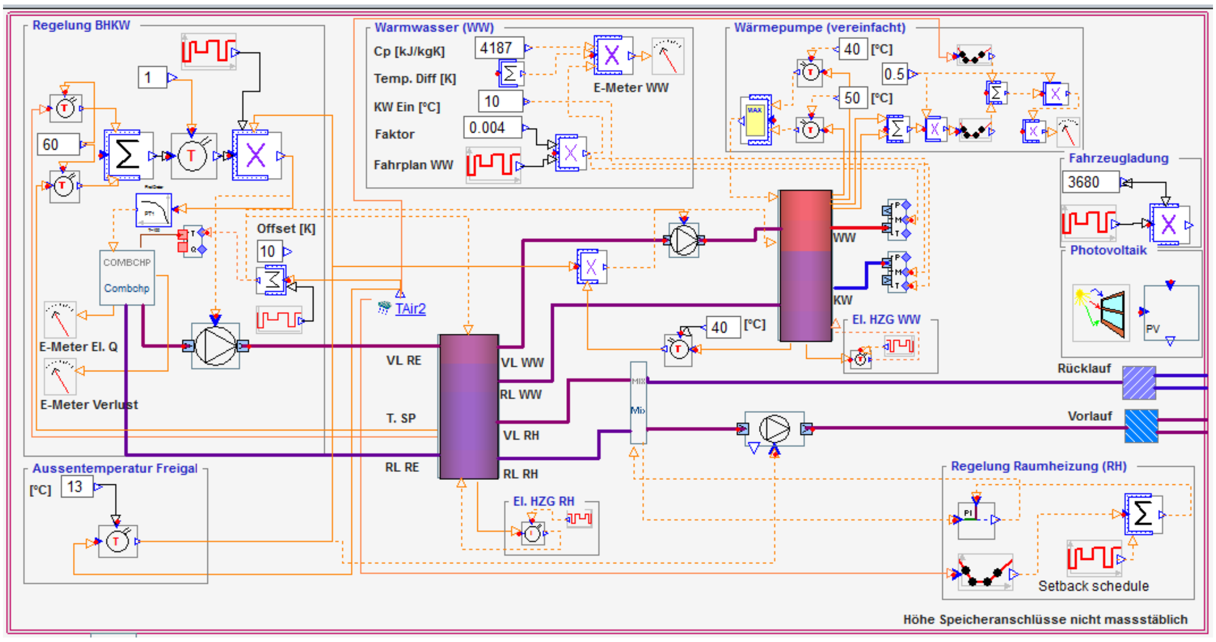

Figure 7 Graphic representation of the model of the whole energy supply in the simulation program IDA-ICE.

RESULTS

Primary Energy Consumption and Environmental Impact

The evaluation of the results was done according to the method common and accepted in the country (Frischknecht et. al., 2008).

For grid electricity, the Swiss consumption mix is used. The high portion of imported electricity due to the active international trading of electricity, of which the provenience is not known, is charged by convention with the values of the European ENTSU electricity mix. This explains the relatively low portion of renewable primary energy in the following presentations.

Figure 8 shows the comparison of the primary energy consumption of the CHP scenarios with the reference scenarios. Some interesting conclusions can be derived from this:

- The primary energy consumption for the „Minergie-P“ standard is (also for the reference scenarios) not lower than for the current regulation standard “MuKEn”. This can be explained by the fact that the regulations require quite a high insulation standard. On the demand side the “Minergie-P” value is smaller, but on the primary energy side this is compensated by higher consumptions of electricity e.g. for the ventilation system.
- The CHP scenarios have roughly the same primary energy consumption as the progressive reference scenario.

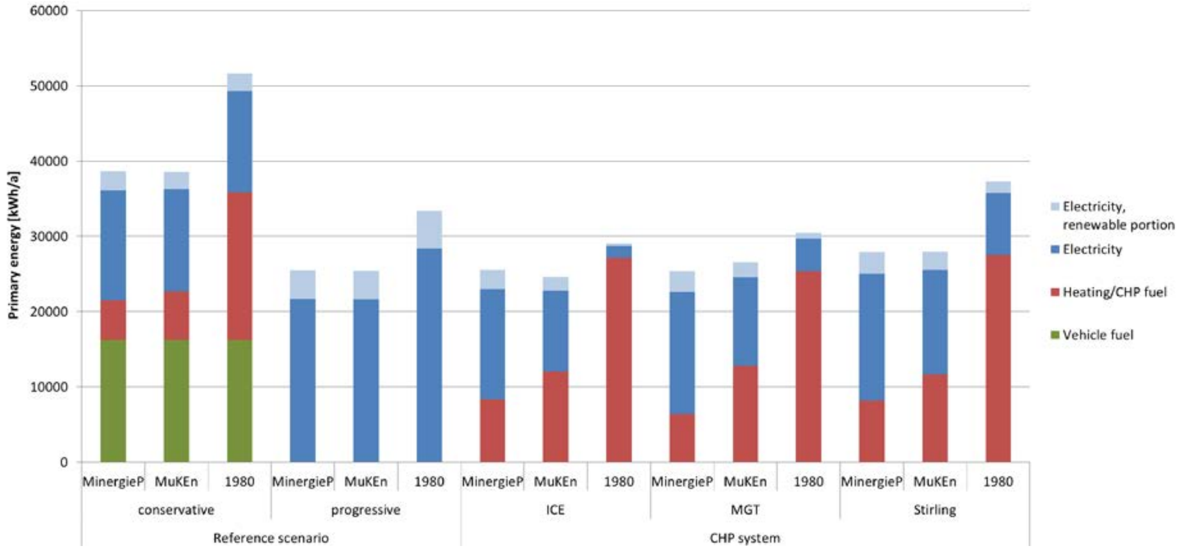

Figure 8 Primary energy consumption for heating, DHW, household electricity and mobility, differentiated according to the building energy standards (Swiss consumption electricity mix / natural gas)

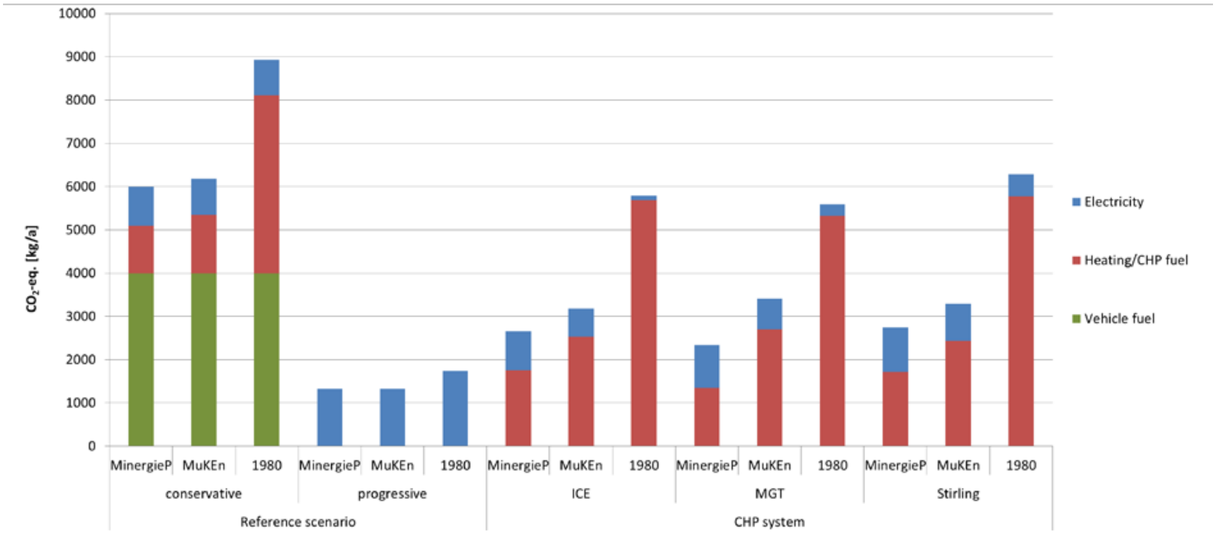

Figure 9 Greenhouse gas emissions for heating, DHW, household electricity and mobility, differentiated according to the building energy standards (Swiss consumption electricity mix / natural gas)

- The fuel consumption of the CHP units increases as expected with decreasing energetic standard of the building. Accordingly, the contribution to the demand of electricity increases, which results in a decreas of consumption of grid electricity. In the case of the best electric efficiency (internal combustion engine, “ICE”), the demand of electric energy is, balanced over the year, almost completely self- covered (by CHP and PV).
- If only the non renewable primary energy is considered, the "progressive" reference scenario has a slight advantage

Figure 9 shows the greenhouse gas emissions for the same variants. Thanks to the relatively clean electric energy, the reference scenario „progressive“ is considerably better than the CHP scenarios is this respect, the latter all being operated with natural gas in this comparison. These have still a clear advantage over the “conservative” reference scenario.

In figures 10 and 11, the systems for the ‚MuKEn‘ energetic standard are compared in respect of primary energy consumption and greenhouse gas emissions, using different energy carriers.

Figure 10 shows that the CHP systems operated with biogas and covering the rest demand of electricity by eco electricity (mix of 80% hydro, 2%PV and 18% biogas CHP) require by far the lowest primary energy input.

If only the non renewable portion is considered, and also for the GHG emissions (figure 11), the scenario with the wood pellet fired stirling CHP and the rest covered by eco electricity has the lowest value. Also low CO_2 values, but double as high, have the scenarios with wood pellet fired CHP and Swiss grid electricity and the “progressive” reference scenario with Swiss grid electricity. High emissions can be seen for all energy carriers in combination with a gas boiler and for all scenarios with the European ENTSO electricity mix.

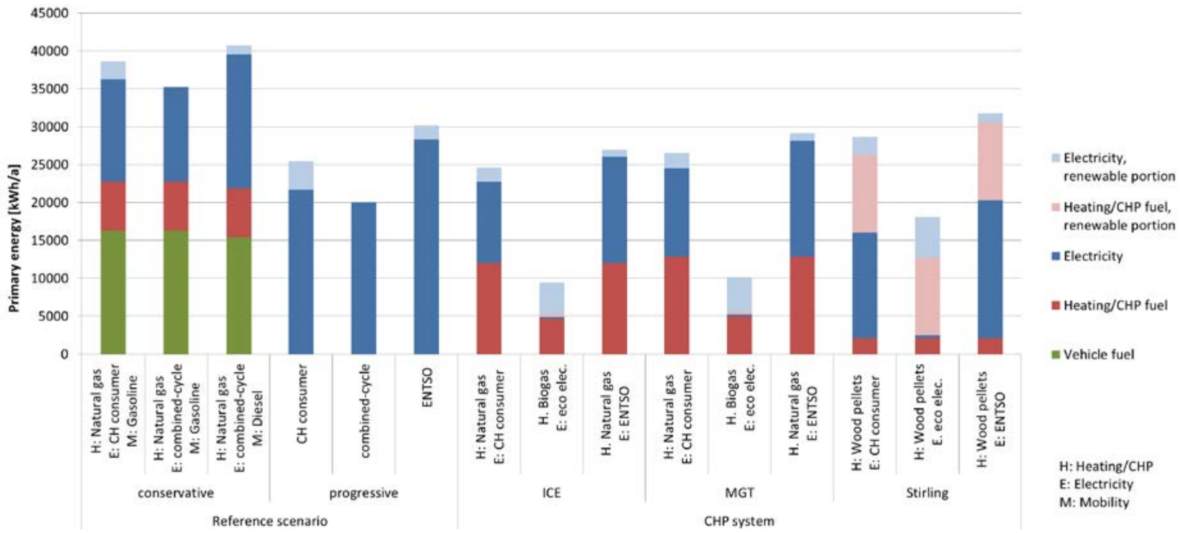

Figure 10 Primary energy consumption for different energy carriers, energy standard ‚MuKEn‘

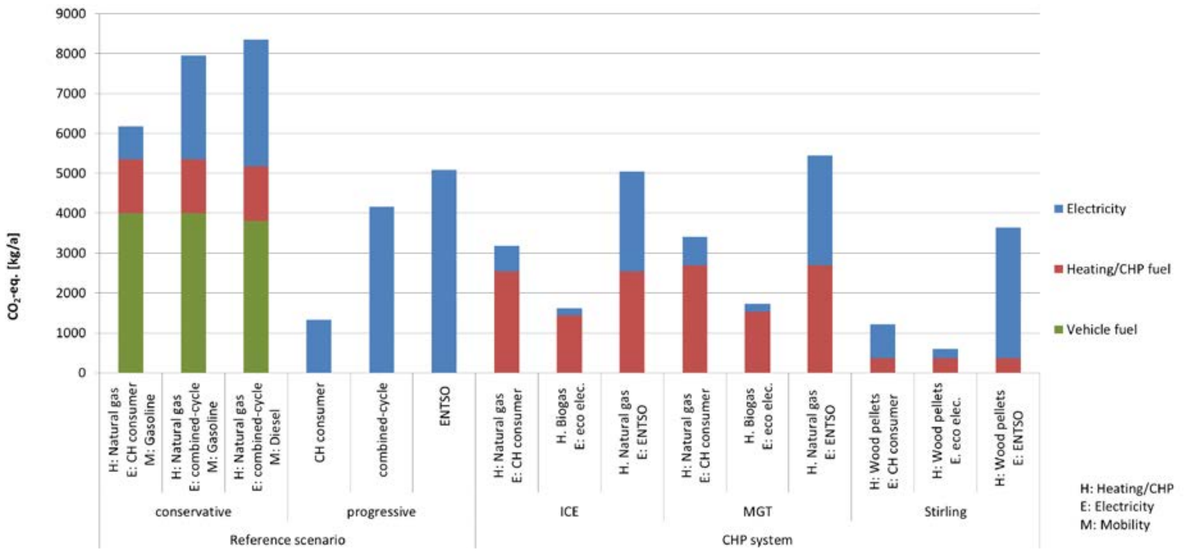

Figure 11 Greenhouse gas emissions for different energy carriers, energy standard ‚MuKEn‘

Synchrony of Electricity Production and Vehicle Battery Charging

In the results shonw above the contributions of the CHP and PV are shown as an annual balance. But due to the annual and daily asynchronity of the demand and production the prodiced electricity is tempararily fed to the grid and consumed from the grid at oher times.

Figure 12 shows the yearly distribution of the electricity production for the energetic standard „MuKEn“. It is visible that this is relatively equalized. In comparison to the houshold electricity demand (which varies due to the assumptions in the standard use data) there is a gap during the autumn months. The mobility use is not covered and not shown here. For the other energetic standards there is an overproduction ("1980") or an even bigger gap ("Minergie-P") during the winter season.

But also the monthly resolution of figure 12 is misleading. The average self-coverage is much lower. The daily profiles in figure 13 illustrate this and show also the possibilities for improvements.

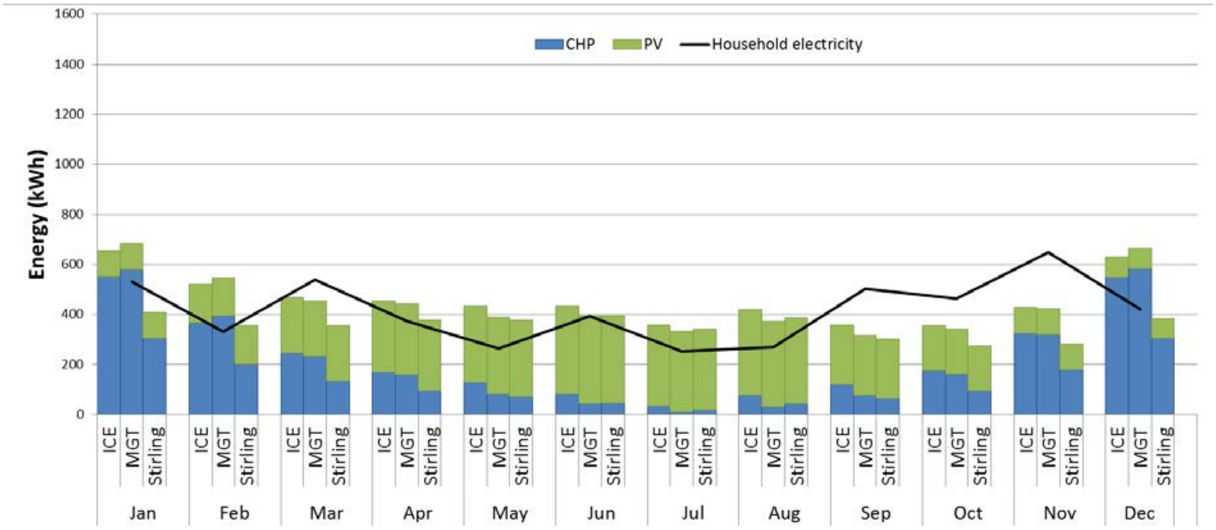

Figure 12 Annual distribution of the electricity production by PV and CHP for energetic standard „MuKEn“

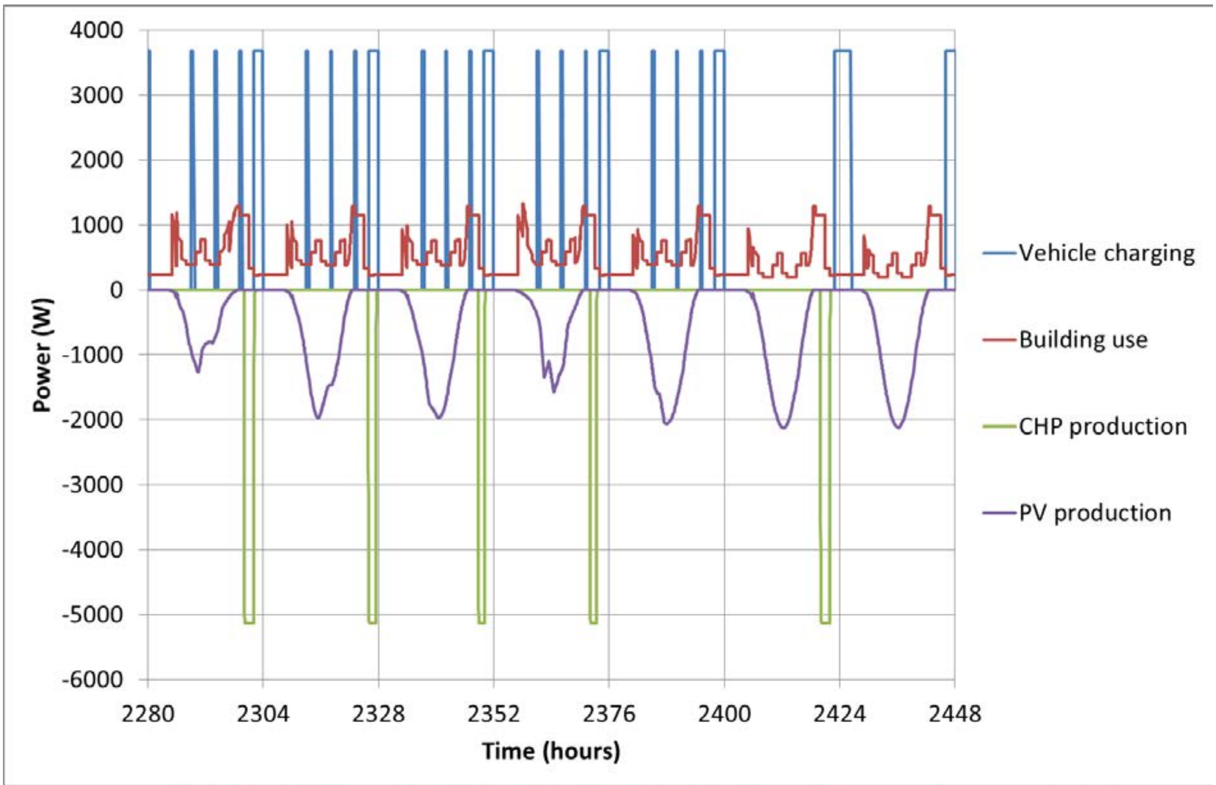

Figure 13 Profile of building electricity demand, vehicle battery charging and electricity production during a week in April (CHP operation limited to 9 pm to 6 am)

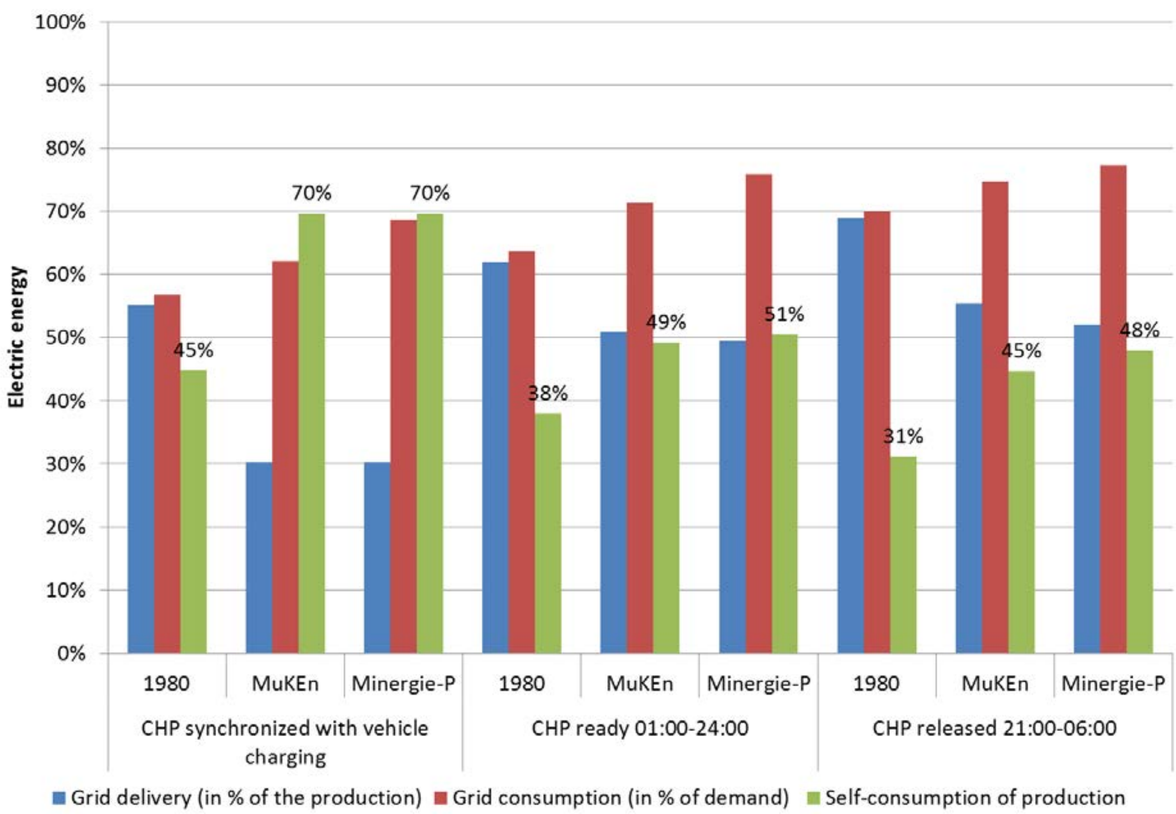

Figure 14 Grid load by the PV/CHP electricity production: proportions of electricity delivered to the grid, consumed from the grid and self-consumed

The electricity generation by CHP and PV occur largely asynchronously to the demand for household and vehicle battery charging. The operation of the CHP unit was limited to the time between 9 pm and 6 am. This requires a thermal storage of the size of a daily heating/DHW demand for the produced heat. If the CHP operation is not limited, the distribution is even more random. The one day storage allows to better synchronize the CHP operation to the vehicle battery charging. This means, operation is only released when the vehicle is connected to the grid.

Figure 14 shows the portions of electricity which are self-consumed, delivered to the grid and consumed from the grid. With the synchronized release of the CHP operation, the self-coverage can be increased significantly, up to the value of 70% for the energetic standards „MuKEn“ and „Minergie-P“.

RANGE EXTENDER: THE VEHICLE AS A CONSUMER AND PRODUCER

In the frame of a bachelor diploma thesis conducted in parallel (Klauz und Peinsold, 2011), the scope was widened in the sense that the combustion engine used on the vehicle as a range extender is also used as a CHP during the time when the vehicle is out of operation. The operational and energetic conclusions become largely similar to the variant with the synchronized operation of the stationary engine. However, the technical connection to the building installation becomes a challenge, especially under the requirement of an easy to handle "plug and play" solution. A proposal was developed for this (figure 15).

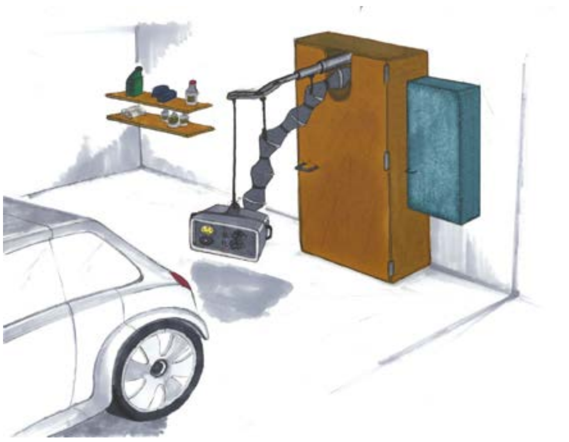

Figure 15 Plug & play solution for the connection of theelectric vehicle with range extender to the building installation

CONCLUSION

With the detailed modelling and simulation of a residential unit and the connected mobility, different variants of micro CHP systems could be compared to reference scenarios and evaluated in respect of their primary energy consumption and greenhouse gas emissions.

It has been shown that the micro CHP systems are equivalent to a progressive reference scenario with heat pump, PV and electric vehicle in respect of the primary energy consumption. However, depending on the provenience of the electricity, the result can turn out different. In respect of greenhouse gas emissions, they are superior, especially with the use of renewable energy carriers such as biogas and wood pellets.

They can complement the electricity production of PV ideally in the annual course. For this, a too rigorous insulation standard of the building is rather disadvantageous.

By adequate control measures, especially the synchronization of the CHP operation with the charging of the electric vehicle, the self-coverage of the electricity can be increased to up to 70%, which reduces the grid load significantly. The condition for this is a thermal storage of the size of a maximum daily heating/DHW energy demand.

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