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# **Synergies and Conflicts of Integrating Electromobility and Renewable Energies into the Urban Micro Grid at Train Station Berlin Südkreuz**

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## **Summary**

For the Intelligent Mobility Station Berlin Südkreuz simulation-based optimization identified conflicts and synergies of integrating electromobility and renewable energy into a micro grid. Results show that the increase of autonomy is proportional with battery capacity used for storing excess energy. Optimization shows that renewable energy generation and their appropriate curtailment should be preferred. However, it can ultimately lead to overall system life cycle emissions comparable to those of the partly fossil energy mix from the public grid. Consequentially we derive general proposals of how to optimally combine storing, curtailing and feeding-in of renewable energy in a local micro grid with electromobility.

*Keywords: optimization, renewable, BEV, energy, demonstration*

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## **1 Introduction**

The challenge of providing sustainable mobility means more than simply replacing internal combustion engine vehicles with their electric counterparts. In order for electric mobility to succeed as a true sustainable alternative its introduction must be complemented by a more intermodal approach of transportation [1] as well as a suitable supply of renewable energy [2].

As a connecting hub of several intermodal mobility options, the train station Berlin Südkreuz experiences a high throughput of passengers and visitors who are provided with long range as well as public and private transportation options. The showcase research project Intelligent Mobility Station Berlin Südkreuz addresses the integration of electromobility and locally generated renewable energy. In the past three years Reiner Lemoine Institut, Deutsche Bahn and Schneider Electric together with several other partners installed renewable energy generation units, such as photovoltaic generators (PV) and small wind turbines (SWT) as well as a battery electric storage system (BESS) and an electric car sharing platform as part of a micro grid at the train station (see figure 1).

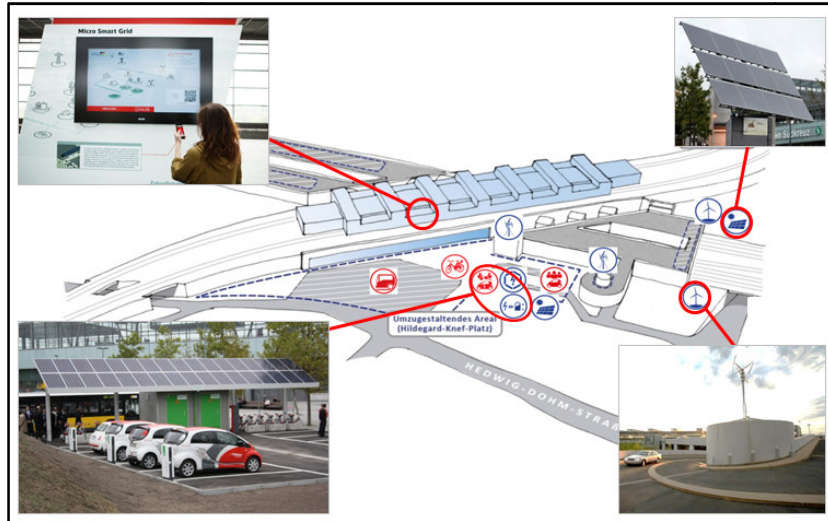


Figure 1: Micro grid at train station Berlin Südkreuz

Table 1: Overview of the installed components parameters

		SWT1	SWT2	SWT3	PV1	PV1	Sto	Grid
number	-	1	1	2	1	1	1	
type	-	DHR	DHR	HAWT	MSI	PSI	Li	
lifetime	<i>a</i>	20	20	20	20	20	10	
$\eta$	%	97	97	-	13.9	15	95	
P	$kW_{el}$	1	1	6	7.5	8.5		
height	<i>m</i>	20	20	20	5	5		
azimuth	-				201°	-		
tilt	-				15°	-		
c-rate	<i>1/h</i>						2	
capacity	<i>kWh</i>						50	
SOC <sub>l</sub>	-						0.15	
SOC <sub>u</sub>	-						0.95	
$P_{standby}$	<i>kW</i>	0	0	0	0	0	1	
CapEx	<i>EUR/kW</i>	25653	25993	5833	4000	5205		
	<i>EUR/kWh</i>						2748	
OpEx	<i>EUR/a</i>	125	125	340	200	200	2000	
	<i>EUR/kWh</i>							0.25
WACC	-	0.06	0.06	0.06	0.06	0.06	0.06	
LCE	<i>t CO<sub>2</sub>-eq./kW</i>	4.19	4.19	2.35	1.5	1.5		
	<i>kg CO<sub>2</sub>-eq./kWh</i>						75	0.535

## 2 Methodology

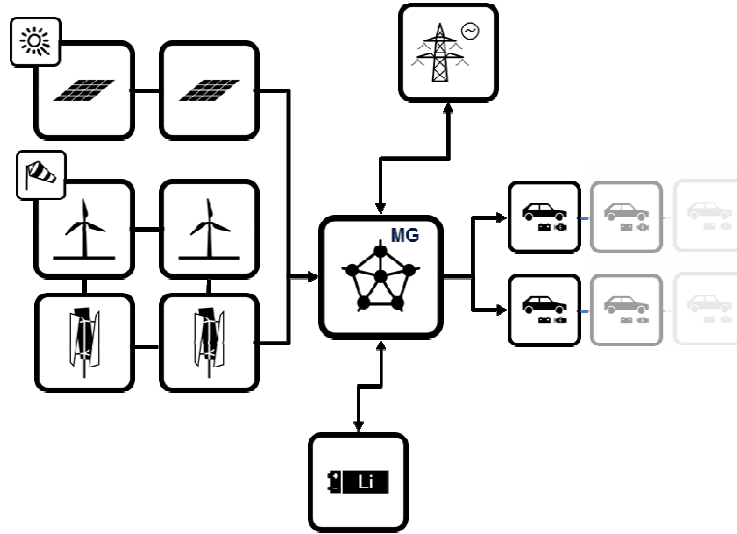


Figure 2: Topology of the installed micro grid within the research project

In this paper the micro grid's optimal topology is determined and analyzed for the conflicting objectives of levelized cost of electricity (LCOE) minimization and time-based autonomy maximization. A year-based simulation model of the micro grid is used to optimize the sizing of the system's components via a multi-objective evolutionary algorithm [3], producing a two-dimensional optimal pareto curve. The shema of the modelling is shown in figure 2, which includes ten charging points for electric vehicles. Results are then validated and discussed on the basis of measurement data of the electric vehicle fleet as well as the micro grid's hosting capacity.

### 2.1 Levelized cost of electricity (LCOE)

Levelized cost of electricity in this paper describes the cost per electrical energy unit used by the microgrid's total load and takes into account all capital and operational expenditures (levelized over all years within the planning horizon) of all components that are part of the optimization process [4]. The costs include not only those of energy generation facilities but of charging infrastructure for the electric vehicles as well.

$$LCOE = \frac{\sum_i A n_i}{\sum_{8760h} E_{load}} \quad (1)$$

### 2.2 Time-based autarky (TA)

Time-based autarky describes the degree of self-sufficiency of the microgrid and is determined according to the overall time span in which power is neither taken from nor fed into the overlying electricity grid level.

$$TA = \frac{\sum_{j=1}^{8760h} t_j(P_{grid}=0)}{8760h} \quad (2)$$

## 3 Results

Results show that via topology optimization autonomy can be increased from 61.5 % to 89.1 % without increasing LCOE compared to the system's original design (see fig. 3). Similarly, the system's LCOE can be reduced by 76 % without compromising autonomy. This effect is due to the electric vehicles load

demand, which allows implementing lesser battery capacity than planned within the project. Results also demonstrate that ultimate autonomy is comparatively cost-intensive; decreasing autonomy from 100 % to 98.2 % and 89.6 % cuts LCOE by 34 % and 52 %, respectively. BESS is identified as the main cost driver as its capacity increases exponentially with increasing autonomy. While at lower costs mainly PV and BESS are employed, SWTs are found to be a cost-efficient complement to the system for higher autonomy. Furthermore results show that even though curtailment of renewable power can help lower cost while maintaining autonomy, it can ultimately lead to overall system life cycle emissions comparable to those of the partly fossil energy mix from the overlying grid level.

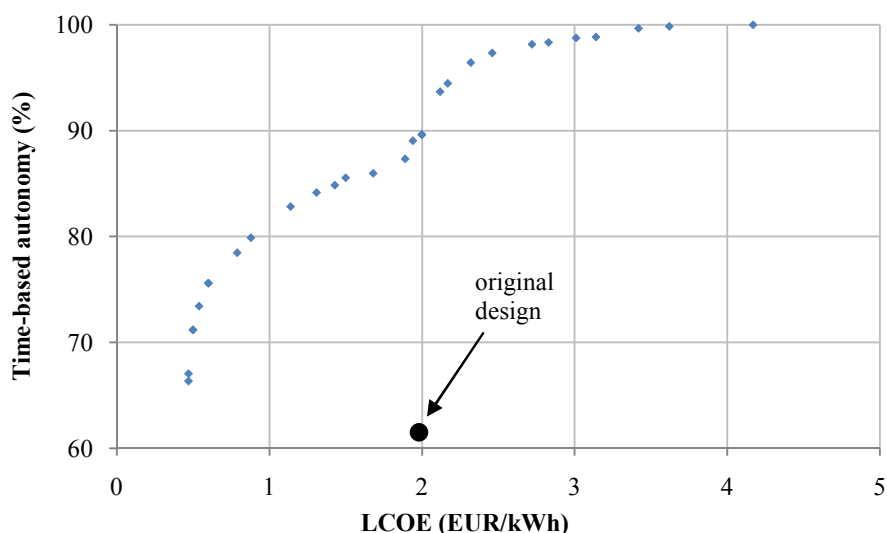


Figure 3: Optimized trade-off between the system's LCOE and time-based autonomy

## 4 Discussion

The overall results suggest that a combination of storing, curtailing and feeding-in of renewable energy is the basis for a best compromise of economic feasibility, ecological benefit as well as self-sufficiency performance in a local micro grid. In fact, the current control strategy of the real Südkreuz micro grid's BESS is set to supply high load peaks through charging of electric vehicles (peak shaving). This is one of many alternative approaches to the one aimed solely at increasing self-sufficiency by blindly storing of excess renewable generation for later times.

For simulation and optimization purposes a load curve for charging of the electric vehicle fleet was synthesized based on historic booking data from electric and plug-in hybrid vehicles. Figure 4 indicates why, as a result of optimization, the combination of PV and BESS might have shown to be the favorable choice for supplying the micro grid: electric vehicle charging is mainly conducted in the evening (8 pm) with further peaks at approx. 8 am and 2 pm. In order to validate the synthesized load curve as well as the optimization results, charging behavior within the electric vehicle fleet was measured for the period of August to November 2015. Even though mean power values are significantly lower than in the synthesized load, load peaks are comparatively congruent, climaxing at 9 am, 2 pm and 6 pm.

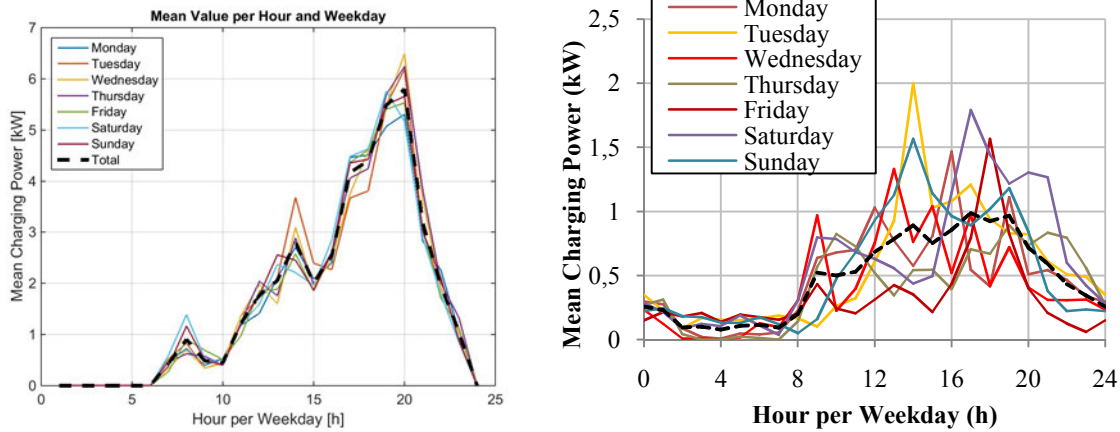


Figure 4: Mean charging power of electric vehicle fleet, synthesized (left) as well measured data (right)

In order to further ensure the applicability of optimization results to the real micro grid, a load flow analysis was conducted based on measured data of the existing renewable energy plants and electric vehicles, as well as parameters of the local grid provided by the grid operator. Results show, that the potential for additional electric vehicles and renewable energy plants is substantial, without the need of further grid extension or improvement regarding the time based congruency of EV charging and renewable energy generation.

## Acknowledgments

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## Nomenclature

$An$	levelized annual cost
$BESS$	battery electric storage system
$CapEx$	Capital expenditure
$E$	energy demand
$ev$	Electric vehicle
$i$	component
$j$	component
$HAWT$	horizontal axis wind turbine
$l$	lower limit
$LCE$	life cycle emissions
$LCOE$	levelized cost of energy
$Li$	lithium ion battery
$OpEx$	Operational expenditure
$MG$	micro grid
$MSI$	mono-crystalline silicon
$\eta$	efficiency
$P$	power
$PV$	photovoltaic
$SOC$	state of charge
$Sto$	storage
$SWT$	small wind turbine
$t$	time step
$u$	Upper limit
$WACC$	weighted average cost of capital

## References

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## Authors



Having graduated from TU Berlin (M.Sc. Mechanical Engineering) Norman Pieniak is working at RLI since 2012. In the beginning he developed several test beds for small wind turbines and battery electric storage systems. As of January 2015 he examined electric mobility scenarios stated at the train station Berlin Südkreuz considering renewable energy generation and the local public transport.



Alexander is a PhD student at the Chair for Energy Process Engineering and Conversion Technologies for Renewable Energy (EVUR) at Technische Universität Berlin. Since January 2015 he has been researching with the RLI in the field of mobility with renewable energy focusing on optimization of hybrid energy and mobility systems. He developed an evolutionary multi-objective optimization algorithm for RLI's simulation framework SMOOTH.



As of December 2014 Florian Schaller works at RLI as a researcher and project manager in the field of mobility with renewable energy. After finishing his master's degree he worked as a product manager for a residential PV storage system and as project manager of two research projects. Florian mainly works on the integration of new electric mobility concepts, especially in combination with smart grids