CARBON NEUTRAL UNIVERSITIES – VISION OR UTOPIA ?

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1. Introduction

Current German climate policy targets are aimed at a reduction of the whole buildings sector's greenhouse gas (GHG) emissions by 55 % until 2030 and at least 80 % until 2050, compared to the reference year 1990. According to the principal "leadership by example" in 2008 the government of Hesse decided to become carbon neutral already by 2030. Beside the whole federal state administration, this project includes the twelve public universities located in Hesse as well. One year earlier the same government brought up a comprehensive infrastructure program for its universities. Until 2020 an amount of three billion Euros will be invested to new and replacement buildings as well as in retrofits and refurbishments of existing ones. Up to now it is quite unclear whether and how these two programs support each other or if there is a conflict of interests.

However, the boundary conditions concerning GHG reductions of the Hessian universities are promising. But until now, just the terminology of carbon neutrality is quite confusing. Standardization for GHG accounting is still in its infancy. Furthermore, especially additionality and irreversibility of measures to offset GHG emissions are discussed controversially. But apart from these discussions, it is hardly deniable that reducing the climate impact of the university buildings needs to take the key role within the climate protection strategy, because their energy use is responsible for most of the federal state administration's as well as the universities' GHG emissions.

Thus, the net zero energy buildings (NZEB) seem to be the appropriate concept as well as a prerequisite for a balanced GHG inventory. With their usually given campus structure, universities offer the advantage that supply and demand of associated buildings can be compensated with each other. Furthermore, they can take advantage from economies of scale by using a common power generation (Voss/Musall 2011). The modernization program opens up the chance to exploit energy saving potential on a large scale. But due to an increasing number of students as well as a growth of energy intensive research facilities it is questionable if expected energy efficiency progress will be caught up by rebound effects again.

2. Key role of university buildings

The first common quantification of the GHG inventory for the federal state administration of Hesse was published in the beginning of 2011 (HMdF 2011). The quantification was done for the base year 2008 according to the methods of The Greenhouse Gas Protocol. The organizational boundaries were defined according to a factory gate approach. This means, that only emission sources were included, which the government or the universities are able to influence directly. Beside the buildings emissions, the transport emissions caused directly by the car pool as well as indirectly by business trips were quantified.

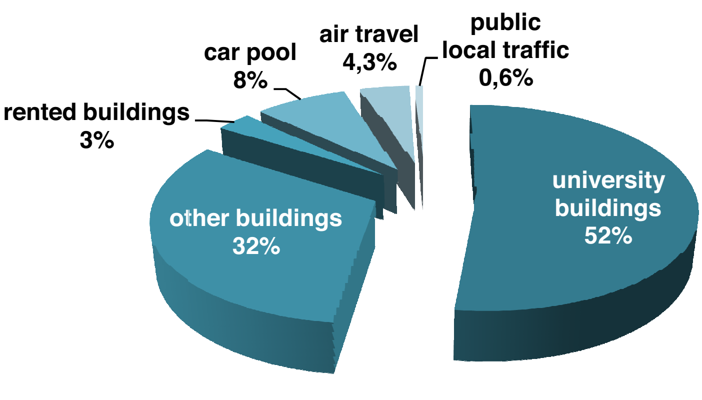


Figure 1: Carbon footprint of the federal state administration of Hesse in 2008

The survey includes some methodological weaknesses and systematic failures. Without going into details, just two examples: The emissions of on-site combined heat and power (CHP) units were overestimated systematically. For one location an individual emission factor for district heating was used provided by the local energy supplier, for all others a general “synthetic” emission factor for the German average district heating supply (see table 1).

However, the results show that university buildings are responsible for about 50 % of the whole federal state administration’s GHG inventory (see figure 1). Looking at the universities, buildings emissions cause more than 90 % of the universities’ recent carbon footprint.

3. Strategy for reducing carbon footprint

Carbon neutrality of buildings can be achieved by several measures. In general it depends on individual boundary conditions, like actual supply structure, the availability of energy saving potential and alternative energy sources, etc. But in principle four basic elements can be differentiated. These are:

1. **Avoidance** by improving energy efficiency of facilities and buildings as well as minimizing energy demand,
2. **Substitution** by fuel switching from fossil fuels to renewable energy sources,
3. **Feed-in credits** from on-site generation of renewable energy surpluses that replace conventional electricity in the public grid, and
4. **Offsets** outside the organizational boundaries, for example purchase of Renewable Energy Certificates (RECs) or investments in reforestation projects.

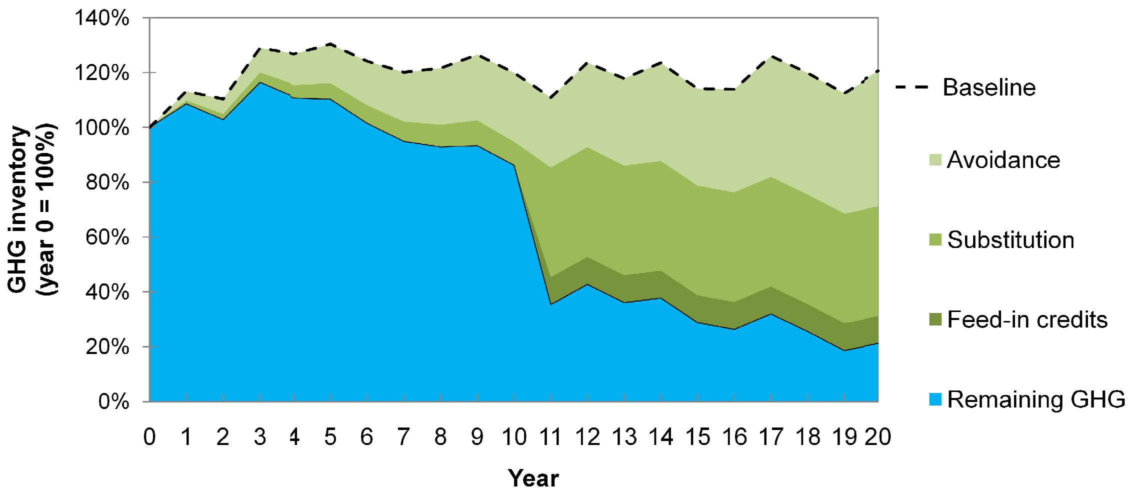


Figure 2: Combination of elements for GHG reduction of buildings (schematically)

In this context, the idea of carbon neutrality is also discussed critically since it is associated with terms like “greenwashing” or “modern day indulgences” (Smith 2007). And indeed, it is questionable if offsets from purchasing RECs really cause measurable net reductions, or reforestation on the other side of the world is an irreversible compensating measure for the duration of at least one century.

Furthermore, offsets make the transformation of buildings and organizations into carbon neutrality possible although they have neither implemented measures to avoid emissions nor to substitute fossil fuels. Such an approach is absolutely contrary to the idea of NZEB as well as principles of carbon neutrality. For these reasons, measures to reduce GHG emissions should be realized in the same order and priority. Correspondingly, offsets should just be limited to the remaining and unavoidable emissions (see figure 2).

4. Status of the university buildings

The current building stock of the Hessian universities consists of about 750 buildings. Overall they represent a wide range of size, utilization and construction year. The major part of these buildings was constructed during the expansion phase of German higher education in the 1960s and 1970s, when most of traditional universities were expanded and a lot of new universities were established ("2nd generation"). Especially the "1st-generation"-universities have to maintain a high share of listed buildings that are underlying restrictions of monument conservation.

4.1. Energy supply

A typical of many larger universities is the classic campus structure in which facilities for research and teaching as well as central services and residence halls are located close to each other. The campus energy supply is usually centralized. The distribution of heat, cooling water and electricity of single buildings is managed on-site and operated by own technical staff.

The analysis of purchased energy of the twelve Hessian universities shows that universities energy consumption is based nearly completely on fossil fuels (see figure 3). The heat supply of buildings is mostly ensured by district heating, natural gas and heating oil. Larger universities often operate own CHP units that ensure on-site base load for heat and electricity. But the major part of electricity demand is purchased from the public grid. Cooling water is usually provided within the buildings by decentralized compressors, rarely by central absorption refrigerators.

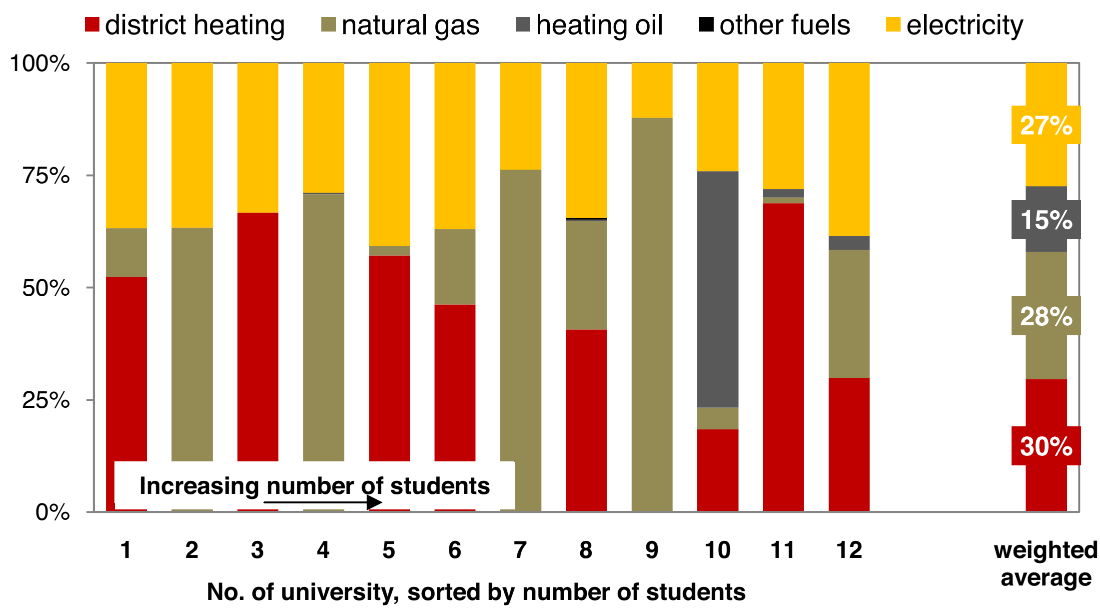


Figure 3: Distribution of purchased energy of Hessian universities

Renewable energy sources do not play a role within today's energy supply of Hessian universities. Indeed, the universities meanwhile purchase electricity with RECs. This general prerequisite was implemented into the statewide tendering procedure in 2009. But matter of fact is that up to now purchasing RECs does not contribute to an additional growth of renewable energy sources and therefore reducing GHG because the actual capacities of existing hydropower plants are more than sufficient to meet the demand (Irrek/Seifried 2007).

Furthermore, some universities have installed photovoltaic (PV-) systems on some of their roofs. But on the one hand the generated PV-electricity would just supply 0.1 % or less of whole universities' electricity demand it is usually fed in the public grid. Therefore it is improving the grid emission factor but not the universities' GHG inventory.

Thus, the following emission factors (as carbon dioxide equivalents → CO_{2e}) were used for the own calculation of the GHG-inventory of Hessian university buildings. The data were taken from the database of The Federal Environment Agency (UBA 2011a).

Table 1: General emission factors for purchased energy in Germany

Energy source	Emission factor [t CO_{2e}/MWh]
District heating	0,218
Natural gas	0,252
Liquid gas	0,277
Heating oil	0,321
Electricity	0,570

In general, these emission factors are no constant values. Especially the rapid expansion of renewable energy sources in the public electricity grid has led to a significant decrease of the corresponding emission factor in Germany. Over the last decade, the specific value per kilowatt-hour was reduced by about 1.5 % per anno. Recent political actions are aimed at a further penetration of renewable energies to the public grid and thus to continue this trend (Nitsch 2007).

In contrast, large technical improvements for heat generators are not to be expected, so that the corresponding emission factors will stay constant. The development of district heating emission factor depends strongly on changes in the corresponding primary energy use, similar to power generation. But in the last years, no significant progress was made concerning increasing the share in energy mix as well as decreasing of emission factors (UBA 2011b). Thus, a decrease of district heating emission factor is even not expectable.

Excluding the buildings of university hospitals the energy consumption of Hessian university buildings amounted to about 570 GWh in 2008. Based on the emission factors in table 1 the total GHG-emissions sum up to nearly 200,000 t/a.

4.2. Energy consumption of buildings

Since the Hessian university buildings were mostly constructed in 1960s and 1970s they don't comply with today's energetic standards. In a first step the energy saving potential can be estimated by comparing the final energy use of the buildings to the corresponding target values, which are provided by national benchmarks (BMVBS 2009). These data were collected to calculate reference values for energy performance certificates differentiated by main utilization.

The actual specific energy consumption values ($e_{actual,h}$ and $e_{actual,e}$) for heat and electricity of each building in kWh/(m² a) were divided by corresponding reference values ($e_{ref,h}$ and $e_{ref,e}$) and calculated as index values (I_h and I_e).

$$e_{actual} = \frac{E_{actual}}{A_{NFA}} \quad \left[\frac{kWh}{m^2\, a}\right] \qquad ; \qquad I = \frac{e_{actual}}{e_{ref}} \cdot 100\%$$

Based on these index values a classification of buildings was done according to the following scheme.

Table 2: Energetic classification of buildings

heat use index I_h	electricity use index I_e	class
$\leq$ 100%	$\leq$ 100%	A
> 100%	$\leq$ 100%	B
$\leq$ 100%	> 100%	C
> 100%	> 100%	D

The index values could be calculated for 443 buildings that are representing 2/3 of total net floor area (NFA) and about 75 % of total buildings emissions. For the rest of the buildings energy metering for heat as well as electricity was not possible. If several buildings have just a single electricity or heat energy meter, the reference values were weighted according to their share of NFA.

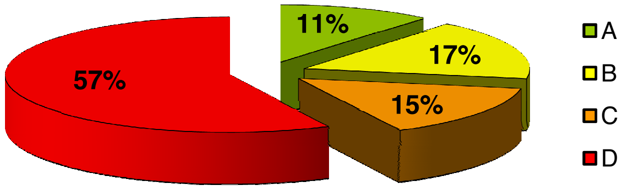


Figure 4: Energetic classification of Hessian university buildings (n = 443)

The results of the analysis show that the majority of the buildings exceed considerably both heat and electricity reference values. Nearly 60 % of the sample's total NFA is classified in category D. This confirms the thesis most buildings have a high demand on refurbishment and probably offer the opportunity for energy saving measures in a large scale. It can be assumed that a systematic refurbishment of the building stock will contribute to GHG reductions.

5. Description of scenarios for future carbon footprint

Overall, four scenarios were deduced. They are based on each other, so that the influence of additional climate protection measures can be quantified. The data and information concerning the current energy use and construction program were provided by the technical departments of the three universities.

The first scenario, "*business-as-usual*", is just including these refurbishments and new constructions for which funding has been assured. Furthermore, small measures that can probably be paid from annual maintenance budgets were taken into account. Major building projects for which universities have tangible elaborated plans but which exceed the secured amount of investment are excluded.

However, in the second scenario, "*master plan*", these constructions and retrofits are included again. In the first and second scenario the following simplified assumptions were made concerning the energy savings and therefore emission reductions that are reached by refurbishments: The specific heat demand will decrease by 30 %, the specific electricity demand by 10 %. For new constructions it is assumed that they achieve the target values of national benchmarks if no other target values were aspired by the universities.

In the third scenario, "*high efficiency buildings*", achievable energy savings were raised towards future energy efficiency target values significantly. Energy savings resulting from refurbishment were doubled so that the heat demand will decrease by 60 % and the electricity demand by 20 %. Moreover, the target values for new constructions are assumed to fall below national benchmarks considerably: the heat demand by -50 % and the electricity demand by -25 %.

In the fourth scenario, "*fuel switch*", it is assumed that in addition to the measures implemented in the third scenario the largest heat generator of each university is replaced or complemented by a CHP unit using biogas as energy source. The related peak demand boiler will use biogas as fuel as well. The CHP units will be dimensioned and operated to meet about 50 % of campus heat demand. Since the on-site generated power will not always meet the universities electricity demand it is assumed that 80 % will be consumed on-site and 20 % will be fed in the public electricity grid.

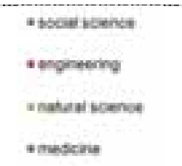
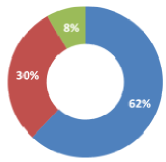
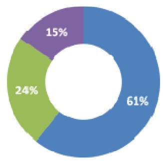
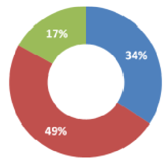
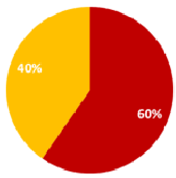
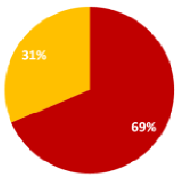
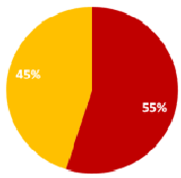
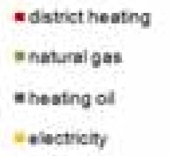
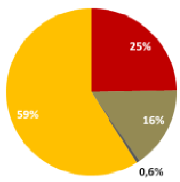
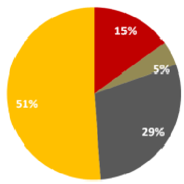
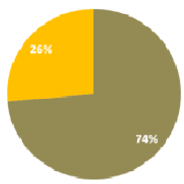
This approach is due to the fact that a high growth of biogas plants is forecasted as well as intended politically (FhG UMSICHT 2009). The advantage is that biogas, purified to bio methane, can be injected in the existing gas grid. Thus, it can be integrated in existing supply structures easily without a general technology change universities have to deal with. The emission factor of bio methane amounts just to one third of the corresponding factor for natural gas. It is assumed that this fuel switch will be realized in 2020, after the most constructions have been finished. Furthermore, it is assumed that universities install PV-systems with 10 kW_p annually, starting in 2012. The specific energy yields of 850 kWh/(kW_p a) will be used completely to meet on-site demand.

6. Results from case studies

The development of energy related GHG inventory is shown by three case studies. Each of them educating about 18,500 students, they can be classified as medium-sized universities. Table 2 gives an overview to the current students enrolled, energy consumption, GHG-emissions and the construction program.

Due to their individual historic development, there are huge differences concerning the curriculum, building structure and facilities. According to the individual conditions of construction year, utilization and energetic status, the intended construction programs are also very different, so that these three case studies are supposed to represent a wide range of universities, at least in Germany.

Table 3: Main data of the Universities of Kassel, Marburg and Darmstadt (winter term 2008/09)

University	**University of Kassel**	**University of Marburg**	**Technical University of Darmstadt**
Established	1971	1527	1877
Characteristics	2nd-generation university, high practical orientation	traditional university, classical curriculum	technical university, high research activity
Number of students	17,616	18,933	18,390
			
Energy use [MWh/a] (incl. on-site CHP generation)	51,700	123,800	93,100
			
GHG emissions [t/a]	18,300	43,200	31,200
			
Number of buildings	85	120	140
Net floor area [m²]	290,000	375,000	420,000
Construction program until 2030 (master plan)			
Refurbishment [m²]	76,500	182,000	233,000
New construction [m²]	81,000	123,500	55,000
Termination/demolition [m²]	62,000	131,500	0

6.1. Case Study 1 – University of Kassel

The construction program of the University of Kassel is focused mainly on establishing a new campus for natural sciences, next to the current main campus. This measure is supposed to be finished by 2018. In return the old campus for natural science and some other faculties located outside the city center is supposed to be terminated. Thus, several buildings with a NFA of about 80,000 m² have to be constructed.

In a first construction section, several new constructions as well as retrofits of faculties, central services and a residence hall will complement the main campus until 2015, providing the increasing space requirements. In the second construction phase, the new buildings for faculty of natural science will be constructed. Afterwards the old campus will be terminated. A total growth of NFA by +7 % is aspired. Furthermore about 30 % of the building stock is supposed to be refurbished during the next 15 years. The refurbishment rate has a value of about 2 % p.a. until 2020, and then it will decrease to about 1 % p.a.

Scenario calculations show that in the business-as-usual-scenario the GHG emissions will decrease by 13 % until 2030. This reduction is resulting nearly completely from the indirect effect that the emission factor of grid electricity is assumed to decrease. This is even overcompensating overall campus growth. Otherwise a growth of GHG emissions would probably be unavoidable, too.

Only if the university succeeds in constructing the new science campus and in return terminating the old one, it will be possible to reduce GHG inventory by further 11 % (scenario II). But until now, funding for this major project of the university's master plan hasn't been ensured completely. Reaching the more ambitious energetic target values would lead to further GHG reductions of 12 % (scenario III). If the university handles it additionally to switch the current energy supply to a campus biogas supply, it will probably succeed in halving GHG emissions of the building stock until 2030.

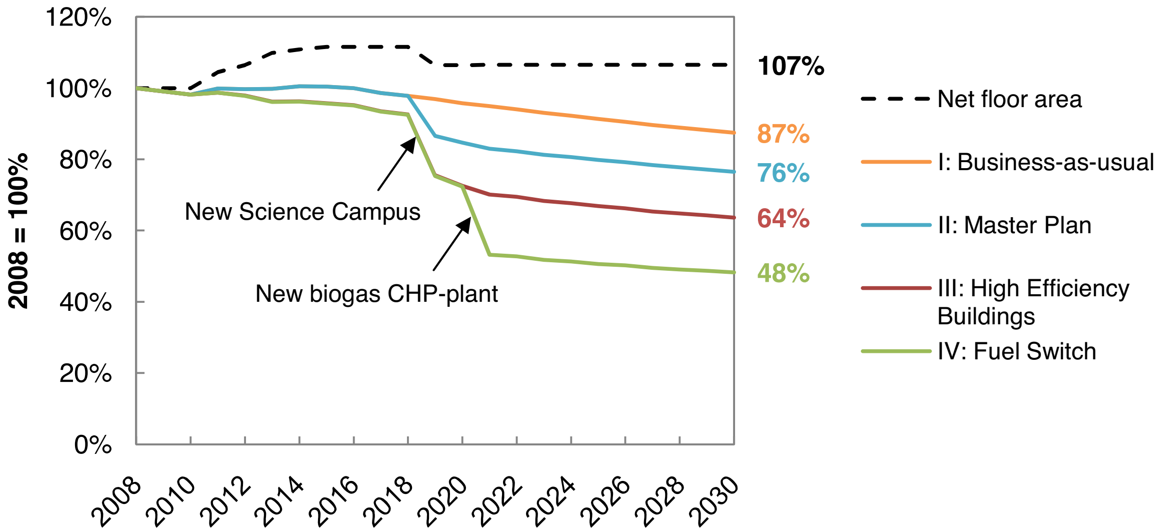


Figure 5: Development of NFA and energy related GHG-emissions of University of Kassel until 2030 in different scenarios

The results of the last scenario show that improving energy efficiency of buildings is a high important element in strategy for GHG mitigation. Furthermore, the installation of PV-systems may be an appropriate measure to underline climate protection efforts to public. But indeed it has no measurable effect on GHG inventory at all.

6.2. Case Study 2 – University of Marburg

Compared to the other case studies, the University of Marburg has the highest share of historic buildings as well as buildings with a poor quality of building structures. Especially the buildings for natural and life sciences which were constructed in the 1970s don't meet today's energetic standards as well as faculty utilization requirements. Therefore these buildings with a NFA of about 60,000 m² are supposed to be replaced by new constructions in the long term.

The university administration is planning the most complex and even most expensive construction program of the three investigated universities. It is including a complete rearrangement of the building stock with a bunch of new constructions as well as the termination of several locations in periphery. In the long term, the main objective is to concentrate the university buildings on one inner-city campus for social sciences and facilities for central services and one campus for natural and life sciences 5 km outside the city.

A specialty of the University of Marburg is that it is the only university of the three case studies that set an own measurable GHG reduction goal: until 2020 they shall be halved. Improving energy efficiency and renewing the energy supply are two of the main topics that are described in the climate action plan.

But the results of scenario calculations show that the own set goal won't probably be achieved, even if the university succeeds in implementing the master plan until 2030 (scenario II). The main reason is that the major part of current secured amount of investment will be spent on several new research facilities and a new central library so that the refurbishment rate of 1.1% p.a. will be quite low.

Further significant energy savings could be reached by improving energy efficiency and by raising the refurbishments rate to a higher level. Beyond this, the university needs to ensure funding especially for the aspired replacement constructions of the buildings for the faculty of biology. Moreover, the energy supply for the natural and life science campus has to be renewed completely. The university already worked out tangible plans even including the use of renewable sources. But funding has not been ensured, yet. If the university administration succeeds especially in solving these financial challenges, it will probably be possible to achieve GHG reductions of more than 50 % until 2030 compared to 2008.

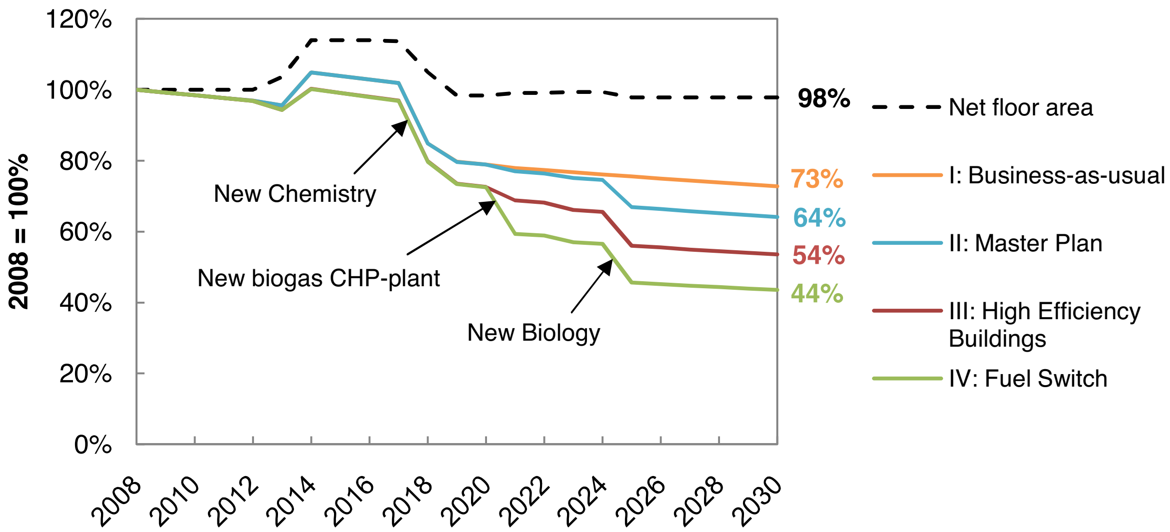


Figure 7: Development of NFA and energy related GHG-emissions of University of Marburg until 2030 in different scenarios

6.3. Case Study 3 – Technical University of Darmstadt

According to its profile as well as external rankings, the Technical University of Darmstadt is one of the most excellent universities in Germany, especially in the field of third-party funded research. Due to the main goal to keep and expand this status, the university's construction program is quite simple: The building stock will be maintained in its current form. In the long term the majority of already existing buildings is supposed to be retrofitted and refurbished. Furthermore, in the next few years several new research facilities and central services (main library, lecture hall) will be finished. The total growth of NFA is estimated to about +13 % compared to 2008. A highlight even regarding the GHG inventory (unfortunately in a negative way) is the construction of a new high performance computer (HPC) with a constant power demand of about 1.5 MW.

Since 2005, a specialty on organizational level is that TU Darmstadt is the first and only autonomous university in Germany. In opposite to other universities, the TU Darmstadt manages and finances even major constructions and refurbishments on its own without participation of state authorities. In return the annual budget provided by the government of Hesse was raised correspondingly. On the one hand, this shift in responsibilities offers the university to react more flexible and even faster to changing basic conditions. On the other hand the university administration must set priorities on its own, for example construction of a new building or refurbishment of an existing one.

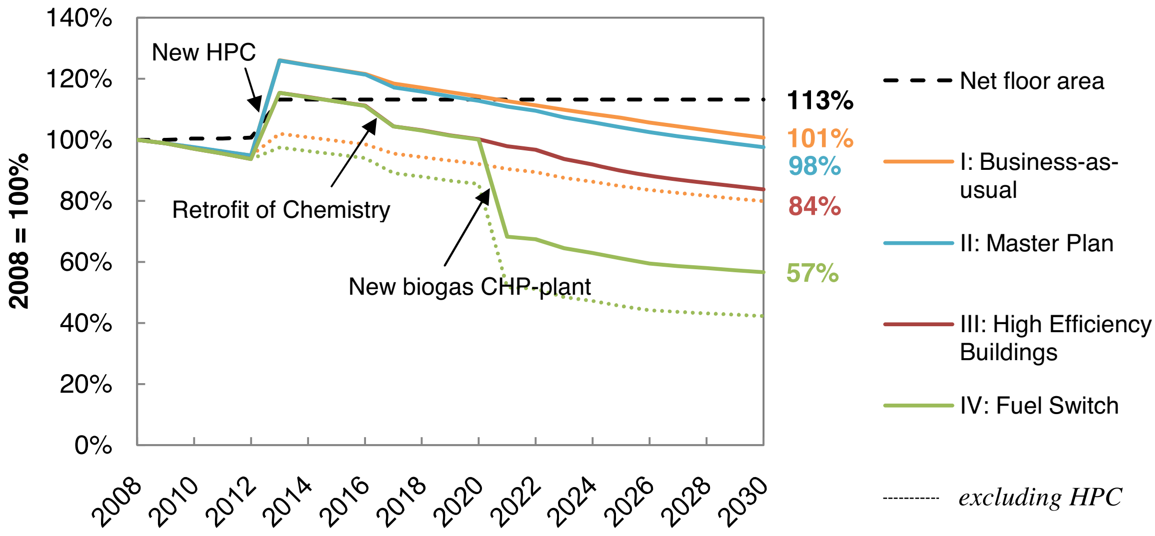


Figure 6: Development of NFA and energy related GHG-emissions of TU Darmstadt until 2030 in different scenarios

Results from scenario calculations show that the new HPC will dominate the university's GHG inventory. After completion in 2012, it can be expected that the GHG-emissions will increase by about 30%. This growth can't be compensated by refurbishment measures at all. Only the anticipated decreasing emission factor for grid electricity ensures reduction of total emissions to 2008 level by 2030. Therefore it is predominately important that the university will succeed to construct and operate the HPC as energy efficient as impossible to reach further energy savings, what is shown by scenario III.

Further significant GHG-reductions will probably just be achievable by switching the energy supply to renewable energy sources. For this, the TU Darmstadt offers very promising conditions because the university is already operating a CHP-plant which supplies the whole university's heat and about 70% of its electricity demand. The HPC will ensure an additional base load, so that the power generation will probably be used almost on-site. Thus, changing the input from natural gas to biogas would decrease GHG emissions by about 30%.

The case study of TU Darmstadt shows impressively that just one single new building might nullify the energy efficiency improvements for years or even decades. If the HPC was excluded from calculations, the GHG emissions would be possibly reduced by about 20% in the business as usual-scenario and even 60% in the "fuel switch"-scenario (see dotted graphs in figure 6). Therefore it will be most important to expand efforts in a systematic and continuous reduction of energy demand and GHG-emissions, as the TU Darmstadt has already done exemplary over the last years. Surely, it will have the flexibility as well as competence to handle this new challenge.

7. Conclusions

The results of the scenario calculations concerning the future carbon footprint of universities show that reaching carbon neutrality will be a really tough goal, if offset measures are understood as well as used as "ultima ratio". Each university has to manage individual challenges according to their development plans and corresponding construction programs. But in general, the case studies show that funding is a major problem. Up to now just about 50% of necessary amount of investment to complete the master plans could be ensured from current modernization programs. Further measures to improve energy efficiency considerably as well as to change the energy supply towards renewable energy sources are not included in these calculations.

Business-as-usual scenarios show that the highest share of GHG reductions will be caused indirectly from decreasing emission factors for purchased electricity. The share of energy efficiency improvements that are implicated from refurbishments or replacement constructions will be quite low because until now the aspired target values are not ambitious enough. Therefore, the total GHG reductions probably won't be sufficient to comply with political long term climate protection goals.

But even if the universities achieve to ensure funding for implementing their master plans with high energy efficiency standards plus a significant share of renewable energy supply by 2030, the energy related GHG emissions probably will amount to "only" about -50 % compared to 2008. Indeed, this would be a great success considering the fact that the number of students as well as energy intensive research activities raise considerably at least by 2020. But it would be still far away from status of carbon neutrality. Reaching further GHG reductions will be the real challenge to be dealt with afterwards. To what extend and what kind of offsets will be implemented needs to be decided on a higher level.

But first of all, universities need to commit their responsibility as role model in climate protection by themselves. A standardized carbon accounting of universities and realistic and obligatory climate reduction goals need to be established on organizational level. Furthermore, universities need to elaborate holistic individual climate action plans as part of their development plans. There is no doubt that universities will have to include all organizational and technical measures that will make GHG reductions possible, even those which have not been discussed in this paper (e.g. floor space management, incentives for energy savings, continuous optimization of facilities to actual needs). Otherwise it seems to be utopia that the climate impact of universities' and especially their buildings as major cause might be minimized.

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