Strategic energy supply of a company location with focus on renewable energies

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ABSTRACT: Climate protection attracts more and more attention in the world public and action is necessary for sustaining the world's environment. To consciously use energy is one way to contribute to a positive development. As the energy supply of buildings covers a significant share of the overall energy use, the European Union releases the Directive 2002/91/EC on the energy performance of buildings, which has to be transposed nationally into law by the European member states. The objective of this work is the development of a sustainable concept for the strategic energy supply of the company with focus on renewable energy sources and against the background of the consequences of Directive 2002/91/EC in Germany. For this purpose the company's situation regarding the resulting German laws (Energy Saving Order and Renewable Energies Heating Act) is assessed by the use of a case study. The first necessary step to ensure the fulfillment of the regulations is the investigation and evaluation of the primary energy fluxes of the heat supply system and the heat grid as an energy system model. Having performed a SWOT-analysis, three strategies are resulting from the external and internal investigation. The purchase of bio-district heat turns out to be the most suitable alternative regarding technical and economical aspects (investment appraisal) to improve the legal situation of the company's location.

I. INTRODUCTION

In the last years the necessity of climate protection attracted more and more notice in the world public. Especially the consequences of the anthropogenic climate change, which cannot be reversed in a short term, could be severe. The increasing emission of greenhouse gases causes a continuous temperature rise on the surface of the earth. Since the age of industrialization carbon dioxide (CO_2), which emerges during fossil combustion, contributes a substantial part in this issue.

This development and its possible impact are not ignored anymore in world's policy since the end of the 20th century. In the so-called "Kyoto-Protocol" from 1997 global objectives for the reduction of greenhouse gases are fixed for the first time. In this frame the European Union as entity is bound to contribute to this movement. (Marquardt, 2011, pp. 17-19) The energy and especially heat supply of buildings in Europe is widely based on fossil combustion. Therefore, in the building sector a huge potential for CO_2-Reduktion can be identified. (Dirk, 2010, p. 1) Hence, a reduction of consumption in this sector would consequently have a huge impact on the overall CO_2-balance. Being aware of that development, the European Union reacts with the introduction of Directive 2002/91/EC on the energy performance of buildings in 2002.

II. LEGAL FRAMEWORK

Directive 2002/91/EC and later Directive 2010/31/EU on the energy performance of buildings by the European Parliament have to be implemented on the national levels. They include a regulation that obligates the consideration of heat supply, energy demand for refrigeration and lighting in the energy balance of a building. Furthermore, the directives force the integration of renewable energy sources or other energy-saving measures like the cogeneration of heat and power into the energy supply of new buildings. (Marquardt, 2011, p. 22)

The German government responds in 2006 with a draft and in 2007 finally with the passage of the amendment of the Energy Saving Regulation (EnEV) (Marquardt, 2011, p. 23). It contains limits for the energy requirement of a building and for the insulation in form of a maximal value for the heat transfer coefficient. In addition, in 2009 the Renewable Energy Heat Act

(REHA) that obligates new buildings to be supplied partially by renewable energy sources is passed. The consequence of not meeting these laws is the refusal of the construction permit. (Marquardt, 2011, p. 23)

The calculation of the limit, contained in the Energy Saving Regulation, for the energy requirement of a building is based on the German standard DIN V 18599. (German Institute for Standardization, 2011) The energy limit refers to the requirement of primary energy for heating, cooling, hot water, ventilation and lighting. (German government, 2013, pp. 37-49) Primary energy refers to the whole life-cycle of the consumed energy including for example processes like extraction, processing and transport. Consequently, the primary energy factor $\boldsymbol{f_p}$ describes the ratio between primary energy requirement and delivered energy requirement (energy available to the supply system to feed the costumers with useable energy). Equation (1) describes the relation mathematically (Dirk, 2010, p. 384)

$$f_p = \frac{\textbf{primary energy requirement}}{\textbf{delivered energy requirement}} \qquad \textbf{(1)}$$

Regarding the heat supply the German standard DIN V 18599 contains primary energy factors for different heat sources which can directly influence the primary energy requirement (e.g. fossil fuel: 1,1; renewable energies: 0,0) limited by the EnEV. (German Institute for Standardization, 2011)

The Renewable Energies Heating Act can, alternatively to the integration of renewable energy sources into the heat supply system, be met by different replacement measures. These include the use of waste heat, a cogeneration unit or district heating. Another option are energy saving measures which describe the positive excess of the Energy Savings Regulation by 15 %. All the options (integration of renewable energies and replacement measures) possess an obligatory share resulting from the act (e.g. solar radiation (only thermal use, PV does not count): 15 %; cogeneration: 50 %; energy saving measures: 15 %). The actual coverage ratio divided by the obligatory share $\boldsymbol{OS_i}$ delivers the degree of fulfillment $\boldsymbol{DF_i}$ of technology $\boldsymbol{i}$. All possibilities can be combined and in that case the degrees of fulfillment are cumulated (see equation (2)). If they reach 100 % the Renewable Energies Heating Act is complied.

$$DF_{total} = \sum_i \frac{CR_i}{OS_i} \qquad \textbf{(2)}$$

Figure 1 summarizes the development of the legal framework regarding the energy performance of buildings in Europe and Germany.

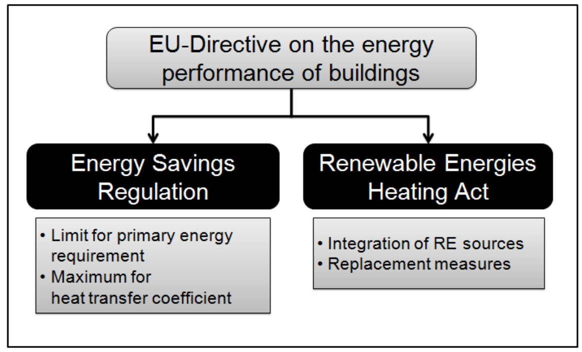

Figure 1: Summary of the legal framework, own design

III. THE COMPANY SITE

Information about the company is restrained in the this public paper.

The location of the company is a production site where industry goods are produced. It covers a huge area with 5 different factory areas and more than 50 buildings. An enormous investment to increase the building stock immensely will be done and by that also the heat supply requirement increases.

The majority of the building stock of the company location is supplied with heat by one energy center. The energy center consists of a combined heat and power unit (put into operation in 2010) with a gas motor and six heating boilers in which gas or oil can be combusted. There are two peak boilers, whose operation point is more variable, to cover peak demand and four regular hot water boilers. The heat supply components are listed in Table 1.

Table 1: Technical data energy center, company internal

	CHP	Hot water boiler	Peak boiler
Units	1	4	2
Fuel	Gas	Gas/oil	Gas/oil
$Power_t$	1,804 kW_{th}	9,360 kW_{th}	6,100 kW_{th}
$Power_{el}$	1,999 kW_{el}	-	-

In the company location a new production building is in the planning stage and will be built within the next years. Its task is to provide production area for production processes.

The new production will be located in the supply area of the energy center. This building serves as a case study in this scientific work. It is used to examine the situation regarding the compliance of the laws on the energy performance of buildings. Building-specific circumstances are not considered and left out in this paper to ensure the transferability to the general situation.

IV. PRESENT LEGAL SITUATION

Energy Savings Regulation

First of all the situation regarding the Energy Savings Regulation is investigated. Its crucial limit is the primary energy requirement of a building. The regulation concerning the heat transfer coefficient is only a structural measure which has to be taken into consideration by the architects.

The primary energy requirement for heating $W_{p,heat}$ can be determined (by the software "Solar-Computer") by the delivered energy $W_{del,heat}$ (47.55 kWh/m²a) and shows a proportional behavior regarding the primary energy factor. The primary energy use for electricity $W_{p,el}$ (37.19 kWh/m²a) is independent of this factor, therefore a linear mathematical relation between the total primary energy requirement $W_{p,total}$ of a building and the primary energy factor $f_{p,FW}$ of the energy center can be deviated. Equation (3) delivers the exact mathematical relation.

$$W_{p,total} = W_{p,el} + W_{p,heat} = W_{p,el} + f_{p,FW} \cdot W_{del,heat} \quad (3)$$

A reference building with an identical geometry and use like the new production building is according to the EnEV (including tightening 2016) not allowed to exceed a primary energy requirement of $\mathbf{W_{p,max}}$ = 87.39 kWh/m²a (calculations done after the DIN V 18599). Taking into account this legal limit, equation (3) is transferred to equation (4) and the limit value for the primary energy factor for a new building to fulfill the criteria of the EnEV can be obtained.

$$f_{p,FW} = \frac{W_{p,max} - W_{p,el}}{W_{del,heat}} = 1.06 \quad (4)$$

Renewable Energies Heating Act

To examine the situation regarding the Renewable Energies Heating Act all components that contribute to the fulfillment have to be identified. The ventilation system is able to recover heat by air exchange, which can be regarded as a replacement measure to meet the REHA requirements. In case of the new production building the air exchange unit can cover 29.8 % of the energy requirement (delivered energy) for heating and cooling. With an obligatory share of 50 % for this measure it can deliver a degree of fulfillment of 59.6 %. Besides the heat recovery, the positive excess of the EnEV is the second factor to help to comply the act. For the determination of the critical value for the primary energy factor to comply the renewable energy heating act (REHA) by exceeding the EnEV, the degree of fulfillment DF of equation (2) has to be decomposed (see equation (5)).

$$DF_{total} = \sum_{i} \frac{CR_i}{OS_i} = \frac{CR_{recovery}}{OS_{recovery}} + \frac{CR_{EnEV}}{OS_{EnEV}} \quad (5)$$

Using equation (5) the necessary Cover Ratio CR_{EnEV} to fulfill the REHA (in case of the new production building) can be determined (see equation (6)).

$$CR_{EnEV} = \left(DF_{total} - \frac{CR_{recovery}}{OS_{recovery}}\right) \cdot OS_{EnEV} = 6.06\,\% \quad (6)$$

Consequently, the annual primary energy requirement of the building has to undercut the reference value by 6.06 %, which corresponds to a consumption of 82.08 kWh/m²a. Equation (7) shows the correlation for the determination of the Coverage Ratio of the contribution of the EnEV based on equation (3):

$$CR_{EnEV} = \frac{W_{p,max} - (W_{p,el} + f_{p,FW} \cdot W_{del,heat})}{W_{p,max}} \quad (7)$$

With the conversion of equation (7) to equation (8) the required primary energy factor $\mathbf{f_{p,FW}}$ to meet all the standards of the laws can be obtained. The value is 0.94.

$$f_{p,FW} = \frac{W_{p,max} \cdot (1 - CR_{EnEV}) - W_{p,el}}{W_{del,heat}} = 0.94 \quad (8)$$

V. IMPROVEMENT MEASURES

Fundamentally, in the consideration of the legal situation existing measures for improvement that do not require any change in inventory (e.g. purchase of new components) must be identified. Inventory neutral procedures do not imply investments in physical technical changes and have therefore to be considered first. In the producing industry it is difficult to implement energy efficiency measures on the consumption side of the heat supply system, because a steady operation of the production processes has the first priority. The energy center is in operation since the year 2010 and has modern technical standards, so the benefit of efficiency measures is also strongly limited. Consequently, the only reasonable inventory neutral procedure is the calculation of the real primary energy factor of the heat supply system (instead of still using the estimated value of 1.10), which is referred to as certification of the energy center (see Figure 2).

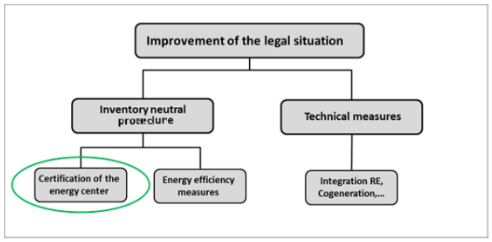

Figure 2: Improvement of the legal situation, own design

At the moment the planners of the company design their projects with a value of $f_{p,FW}$ = 1,10 for the primary energy factor. This is a predetermined value by law for fossil heat supply centers that are not assessed yet (very conservative estimation). With the certification of the factor the actual primary energy factor of the energy center is determined on the base of empirical data.

To calculate the primary energy factor of the heat supply system, the energy center is modelled as an energy system and the analysis is performed based on primary energy fluxes (see Figure 3). (German Institute for Standardization, 2011, p. 68)

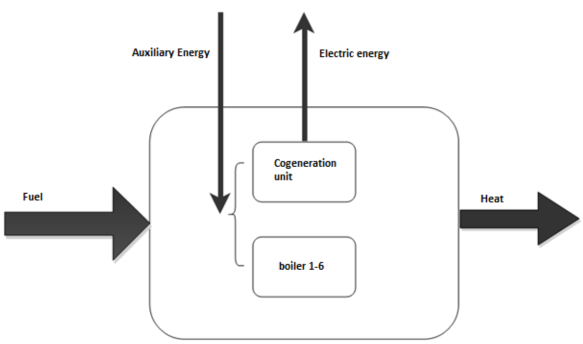

Figure 3: Block diagram of the system, own design

For the energy center the following energy fluxes have to be considered (AGFW FW 309, 2014, p. 8):

- Inserted fuel $W_{Br,i}$ (with regard to the lower heating value of fuel i) with its primary energy factor $f_{P,i}$
- Auxiliary energy A_{HN} (for the maintenance of the heat supply system, e.g. pumps) with the primary energy factor $f_{P,verdr}$ of electric energy
- Generated electric energy inside the system A_{KWK} by the cogeneration unit with the primary energy factor $f_{P,el}$ of electric energy
- Heat energy consumption $Q_{FW,j}$ (measured on the primary side of the heat exchange unit of the supplied building j)

The primary energy factor $f_{P,FW}$ of a heat supply system is determined by the specific energy consumption of the process resulting from the system model. The combusted fuel, the auxiliary energy and the produced electric work by the CHP unit (also in consideration of the respective primary energy factor) are set in relation to the produced heat energy. This approach delivers the following equation (9) (AGFW FW 309, 2014, p. 8):

$$\boldsymbol{f_{p,FW} = \frac{\sum_i W_{Br,i} \cdot f_{P,f} + (A_{HN} - A_{KWK}) \cdot f_{P,i}}{\sum_j Q_{FW,j}}} \qquad \textbf{(9)}$$

To obtain meaningful results the guideline proposes to balance, if possible, all the data from the last three years. With that procedure temporal volatility of the system (changing climate conditions) does not distort the outcomes. For the energy center in all the necessary data is accessible or can be derived from existing values. With the primary energy factor for natural gas and fuel oil ($f_{P,i}$ = 1.1) and for electric energy ($f_{P,el}$ = 2.8) for the balance period (2012-2014) a primary energy factor of $f_{P,FW}$ = 0.97 for the heat supply system can be obtained by equation (9). The calculations are summarized in Table 2. (AGFW FW 309, 2014, p. 8)

Table 2: Calculation primary energy factor, own design

Factor	Value
Fuel input	255,061 MWh
Primary energy use in fuel	280,566 MWh
CHP – net electric work generation	40,273 MWh
Primary energy generation by the CHP unit	112,764 MWh
Auxiliary Energy	1,291 MWh
Primary energy for auxiliary energy	3,614 MWh
Produced heat energy (building side)	177,509 MWh
Primary energy factor	**0.97**

With the primary energy factor of that first improvement measure and the use of equation (3), the Energy Saving Regulation is positively exceeded by 4.6 %.

Considering the Renewable Energies Heating Act (REHA), this positive excess delivers a degree of fulfillment of DF_{EnEV} = 30.7 % besides the contribution of the air exchange unit ($DF_{recovery}$ = 59.6 %).

The next step regarding the REHA is to examine the significance of the CHP unit. It can deliver a coverage ratio with the precondition that the unit can be labeled as “high-efficiency cogeneration” in the sense of the European Directive 2004/8/EC (The Directive is repealed but the calculation methodology is still valid). (Parliament, 2004) The investigation is performed based on the German worksheet "AGFW-Arbeitsblatt FW 308 – Zertifizierung von KWK-Anlagen” (certification of cogeneration units, (AGFW FW 308, 2011)). After executing all necessary steps the cogeneration unit can be classified as highly-efficient (enough primary energy savings) and can therefore contribute to the REHA.

The unit generates 41.394 MWh of heat, while the whole energy center (including the boilers) produces 190.133 MWh of heat energy (grid losses not considered). These values result in a coverage ratio CR_{CHP} of 21,8 %. With the obligatory share OS_{CHP} for cogeneration units of 50 % the unit contributes a degree of fulfillment DF_{CHP} of 43,5 % (calculated with equation (2)).

Considering the contribution of the cogeneration unit (and $DF_{recovery}$ = 59.6 %; DF_{EnEV} = 30.7 %), the new production has, according to equation (10) based on equation (2), the following total degree of fulfillment DF_{total}.

$$\boldsymbol{DF_{total} = DF_{CHP} + DF_{EnEV} + DF_{recovery} = 133.8\,\%} \quad \textbf{(10)}$$

Expansion of the location

Like already explained before, a plan for the expansion of the company location exists. A huge investment of in the building stock enables the construction of several new buildings. A lot of them can possibly be located inside the supply area of the energy center and the heat requirement of the system will increase.

Considering a growth of the heat energy requirement for the supply area of 30 % (see yellow marking in Table 3), the boilers have to cover that increase, as the CHP unit already works at nominal power. For that reason, the additional amount of heat energy has to be generated by the combustion in the boilers. Including their efficiency ($\eta_{boilers,Hu}$ = 85.67 %) to the calculations, by equation (9), resulting from the energy system modelling, the respective primary energy factor $f_{p,FW}$ can be calculated. Table 3 illustrates the results of the calculation.

Table 3: Primary energy factor - expansion, own design

	Existing system	Expansion
Fossil fuel consumption in MWh	255,059	321,641
Heat generation boilers unit in MWh	148,829	205,869
Primary energy factor of oil and gas	1.1	1.1
Electricity generation CHP unit in MWh	40,274	40,274
Heat generation CHP unit in MWh	41,304	41,304
Primary energy factor of electricity	2.8	2.8
Electric consumption system in MWh	1,291	1,678
Primary energy factor of electricity	2,8	2.8
Generated heat (before grid) in MWh	190,133	247,173
Delivered heat consumption in MWh	177,509	230,762
Primary energy factor	**0.97**	**1.06**

With the resulting primary energy factor $f_{p,FW}$ = 1.06 the EnEV is just met but cannot contribute to the fulfillment of the REHA (DF_{EnEV} = 0.0 %) in case of the NPB. For other projects in the supply area even the compliance of the EnEV can be a significant obstacle.

The degree of fulfillment of the CHP unit decreases as well, because it has a smaller share on the overall heat generation (41304/247173 = 16.7 %). This causes the reduction of the degree of fulfillment from 43.5 % to DF_{CHP} = 33.4 %.

With only the coverage shares of the CHP (DF_{CHP} = 33.4 %) unit and the air exchange unit ($DF_{recovery}$ = 59.6 %) left, the application of equation (2) results in a total degree of fulfillment of 93.0 % (see equation (11)).

$$\boldsymbol{DF_{total} = DF_{CHP} + DF_{recovery} = 93.0\,\%} \quad \textbf{(11)}$$

This result proofs (DF_{total} < 1), that the current inventory of heat supply does not ensure a long-term (including an expansion) compliance of the efficiency laws on the energy performance of buildings and therefore further opportunities for improvement have to be considered.

In Figure 4 all possible options according to the statutory requirements are listed. The direct use of renewable energies does either require a significant initial investment or is impossible due to the lack of availability. A further CHP unit is very expensive as well. The use of waste heat depends on the framework conditions of a single building (necessity of heat sources) and can therefore not be considered in the draft of an energy supply concept for the overall system.

Near the company location a biomass fermentation plant will be implemented by the public utility company of the city near the location. After contacting and negotiations with that public company, the opportunity to purchase bio-district heat for the heat supply of the company location is offered.

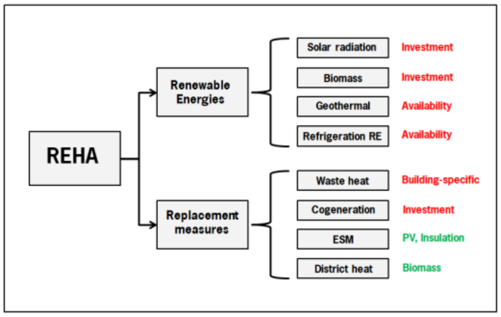

Figure 4: REHA – Improvement options, own design

The whole methodology in this work is performed as a SWOT-analysis. Looking at the internal conditions, a relatively high primary energy requirement of the buildings, an energy center without integration of RE and limited space for an expansion of the building containing the energy center can be identified as weaknesses. Strengths are the existence of a CHP unit and PV plants (including the experience with those technologies) as well as a central heat supply system including all heat supply components.

The external analysis is performed in the examination of the legal situation and the identification of possible improvement measures. The development of the laws on the energy performance of buildings can be seen as an external threat (regulations) but it also contains opportunities as energy from renewable energies does not increase the requirement of primary energy (f_p=0.0). Furthermore, the external analysis delivers opportunity for the company to purchase renewable heat energy.

The SWOT-Analysis finally delivers three different strategies. The implementation of a PV plant is a SO-strategy that combines external opportunities with internal strengths as well as a ST-strategy. Including an external RE energy source in form of bio-district heat is another SO-strategy which can combine the positive aspects of the external and internal analysis. Furthermore, it is a WO-strategy that can transfer weakness to strength. The third identified strategy is the improvement of the insulation to reduce the primary energy requirement. By that WT-strategy the internal weakness is reduced to limit the effect of the external threat. Figure 5 summarizes the SWOT-analysis.

		External Analysis	
SWOT-Matrix Energy laws for buildings		**Opportunities** - positive effect of RE - existence of bio-district heat	**Threats** - increasing legal requirements Decreasing limit for primary energy requirement, Integration of RE
Internal analysis	**Strengths** - existing CHP unit - PV experience - central heat supply	**SO-Strategies** - implementation of a PV plant - include external RE (bio-district) energy source to the central heat supply	**ST-Strategies** - implementation of a PV plant
	Weaknesses - high primary energy requirement - energy center without RE - space limit of energy center	**WO-Strategies** - include external RE (bio-district) energy source to the central heat supply	**WT-Strategies** - improve insulation to meet the limit for primary energy requirement

Figure 5: SWOT-analysis, adapted from (Pelz, 2015)

In conclusion, there are only three suitable technical measures for the improvement of the legal situation of the supply area of energy center in under the actual framework conditions.

VI. CONCEPT DRAFT

In section VI all possible improvement measures concerning the energy efficiency laws on buildings are assessed and compared.

Implementation of a PV plant

By the use of a photovoltaic plant electric energy can be generated inside the system borders and therefore balanced as own production. The implementation requires space and (in case of the mounting on the roof of a building) the necessary structural design to stand its weight. This is the reason why the mounting of a PV unit is not possible on the roof of every building (without an enormous investment in the structure of the respective building).

Energy Saving Regulation

The calculations (performed with the software "Solar-Computer) concerning the compliance of the EnEV for the new production building with a PV plant area of 2,500 m² on the roof of the new production building are available. The own production of electric work reduces the delivered energy requirement of electricity consumers and therefore, considering the primary energy factor for electricity, also the primary energy requirement of the building. A PV area of 2,500 m² decreases the primary energy requirement of the NPB about 8.43 kWh/m²a. With that reduction and the primary energy factor of the energy center in ($f_{p,FW}$ = 0.97) the EnEV can be undercut by 14.5 %.

Renewable Energies Heating Act

By the implementation of the PV-plant the annual primary energy requirement of the building can be reduced by 14.5 %. However, the EnEV-limits can only be undercut by 8.6 % (DA_{EnEV}) due to the heat transfer coefficient of opaque surfaces. This equals, with an obligatory share OS_{EnEV} of 15.0 %, a degree of fulfillment of 57.3 %. On the REHA itself the measure PV has no direct influence as only the thermal use of solar power counts as a contribution measure in sense of the REHA. (German Government II, 2008, pp. 5-6)

Investment appraisal

The investment appraisal for a PV plant is done based on the data existing from other projects. The fixed investment costs consist of the public grid connection costs (50,000 €), the PV modules (0.5 €/W_p) and the system technology (0.7 €/W_p).

With positive future cash-flows due to the saving of electricity costs, Table 4 summarizes the results of the investment appraisal (NPV_{PV} = - 37,913).

Table 4: Calculation NPV, own design

Term	Value	Unit
Investment – Implementation of a PV plant	- 442,340	€
Total investment	**- 442,340**	**€**
Generated annual electric work	319. 68	MWh/a
Electricity price	0.1725	€/kWh
Proportionate apportionment	0.0247	€/kWh
Annual saving due to own generation	**47,249**	**€/a**
Nominal annual interest rate	8.00	%
Project period	15	a
NPV_{PV}	**- 37,913**	**€**
Payback period	**17.96**	**a**

Purchase of bio-district heat[1]

A public utility company of the city (next to the company location) is planning the installation of a biomass fermentation plant in close proximity to the company location. All the bio-waste of the households of the area is collected and disposal fees charged. The public utility company uses the biogas and converts it in a cogeneration unit into "green" electricity and heat. These products are distributed by the utility company.

The result of the negotiations with the public utility company is the possibility at the production location to buy the whole amount of generated heat (Annual work: 7,600 MWh, medium annual power: 867.6 kW) by the cogeneration unit at predetermined conditions and integrate them into the heat grid fed by the energy center.

The public utility company is responsible for planning, construction, investment, maintenance and operation of a district heat pipe utilizing the medium water to the company grounds of the company. On the company grounds the public utility company hands over the heat at predefined conditions (building cost subsidy, basic price and work price) to the production company. The integration of the bio-heat into the heat grid (connection to energy center), the installation and connection of the heat transfer station is the responsibility of the production company.

The bio-heat directly influences the primary energy factor of the heat supply system by reducing the fossil fuel consumption $\mathbf{W_{Br,i}}$ (see Table 5, yellow marking) and introducing bio-heat with a primary energy factor of "zero" (AGFW FW 309, 2014, p. 13). Table 5 proves this statement on the base of equation (9) (resulting from the energy system modelling) for the balance period from 2012 to 2014. The requirement of heat energy generation by fossil fuels by the boilers 1-6 (the CHP unit always runs at nominal power) decreases and by that also the consumption of fuel under consideration of the efficiency of the boilers ($\eta_{boilers,Hu}$ = 85.67 %).

Table 5: Primary energy factor with bio-heat, own design

	Present	Bio-heat
Fossil fuel consumption in MWh	255,059	228,445
Primary energy factor of oil and gas	1.1	1.1
Electricity generation CHP unit in MWh	40,274	40,274
Primary energy factor of electricity	2.8	2.8
Own electric consumption in MWh	1,291	1,291
Primary energy factor of electricity	2.8	2.8
Purchased bio-heat in MWh	0	22,800
Primary energy factor of bio-heat	0	0
Total delivered heat energy in MWh	177,509	177,509
Primary energy factor	**0.97**	**0.80**

The purchase of bio-district heat reduces the primary energy factor $f_{p,FW}$ of the energy center to a value of **0.80**.

Energy Saving Regulation

The improvement of the primary energy factor of the energy center reduces the primary energy requirement for space heating $\mathbf{W_{p,heat}}$. In case of the new production building, the value for the primary energy requirement with the new primary energy factor (0.80) is 75.23

[1] The project information is confidential and is descend from agreements between the project partners during the negotiations

kWh/m²a based on equation (3). This result undercuts the limit for a reference building (87.37 kWh/m²a) by 13.9 % (instead of 4.6 % with the actual value for $f_{p,FW}$). The compliance of the EnEV does not represent a serious obstacle for the NPB if the arranged amount of bio-district heat is purchased and inserted into the system.

Renewable Energies Heating Act

The purchase of bio-district heat can be categorized as sistrict heat or cold (replacement measure) (German Government II, 2008, p. 17)) regarding the REHA, because the heat quality and production fulfill all criteria of the act. The acquired heat energy originates from gaseous biofuel, which is combusted in a CHP unit on a new technical state and therefore has to cover an obligatory share OS_{Bio} of 30 % (German Government II, 2008, pp. 5-6) An annual bio-heat purchase of 7,600 MWh in a period of 3 years delivers a total amount of 22,800 MWh of "green" heat energy. For the same period an overall heat generation of 190.133 MWh by the energy center is measured. The proportionate heat supply by bio-district heat therefore is 12.0 % which corresponds to its coverage ratio CR_{Bio}. The achieved degree of fulfillment by this measure is consequently 40.0 %.

Using equation (2), the degree of fulfillment DF_{SA} for all buildings within the supply area can be determined (see equation (12)). It origins exclusively from the energy center in and consists of the contributions of the bio-district heat and the CHP unit (DF_{CHP} = 43.5 %, actual situation and not expanded). Coverage ratios resulting from building- specific components or measures are not considered.

$$\boldsymbol{DF_{SA}} = \boldsymbol{DF_{Bio}} + \boldsymbol{DF_{CHP}} = \mathbf{40.0}\,\% + \mathbf{43.5}\,\% = \mathbf{83.5}\,\% \qquad \textbf{(12)}$$

Consequently, in the whole supply area of the energy center only 16.5 % of the degree of fulfillment has to be covered building-specifically.

Adding the contributions of heat recovery ($DF_{recovery}$ = 59.6 %) and the positive excess of the EnEV (DF_{EnEV} = 57.3 %), the case study of the new production building proofs that the alternative „Purchase of bio-district heat"ensures (with a very high probability) the compliance of both laws on the energy efficiency of buildings for all construction projects in the supply area of the energy center in factory 2. Even buildings, not equipped with an air exchange unit, can fulfill the criteria of the regulations with this measure (see Figure 6).

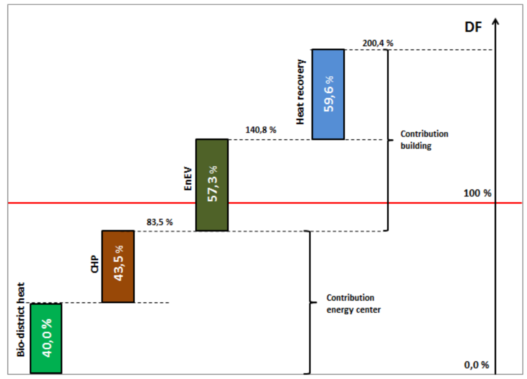

Figure 6: Effects of the bio-district heat on the compliance of the REHA – example NPB, own design

Investment appraisal

The realization of this measure produces fix investments (building cost subsidy, grid connection costs) and additionally negative future cash-flows, due to the price paid for bio-district heat compared to heat generated by the combustion of natural gas (5,00 Cents respectively 3,21 Cents), which lead to a net present value NPV_{Bio} of – 5,87 million € (see Table 6).

Table 6: NPV-bio-district heat, own design

Cost factor	Value	Unit
Construction automation	- 390,200	€
Building cost subsidy	- 250,000	€
Total fix investment	**- 640,200**	**€**
Basic price per month	- 42,020	€/month
Work price for bio-heat	0.05	€/kWh
Work price for natural gas - heat	0.0321	€/kWh
Additional costs for bio-heat	- 7,928	€/month
Running costs per month	**- 49,948**	**€/month**
Nominal annual interest rate:	8,00	%
Relative monthly interest rate:	0,67	%
Product period in years	15	years
Product period in months	180	months
NPV	**- 5,866,859**	**€**

Improvement of the insulation

By an improvement of the building insulation, heat losses through the surfaces of a building can be reduced. Especially in winter an adequate insulation can save high amounts of energy, whereas in summer a level of insulation can also lead to an increase of necessary cooling work, because of heat congestion. Causing contrary effects, this measure can only be implemented in a small scale to save energy.

Energy Saving Regulation

For the case study NPB EnEV-calculations (software "Solar-Computer) are available for different values of

U (heat transfer coefficient). The improvement of the insulation (decreasing the U-value) reduces the delivered energy use for space heating and by that also the primary energy consumption of the building. The planning value for U (opaque surfaces) is 0.256 W/m²K. The annual primary energy requirements are also calculated for a higher U-value of 0.271 W/m²K by the application of the software „Solar-Computer“. A reduction of the U-value by 0.015 W/m²K decreases the annual requirement of delivered energy for space heating by 1.47 kWh/m²a (respectively the primary energy requirement by 1.43 kWh/m²a). By that difference the EnEV can be undercut by 1.6 % more.

Renewable Energies Heating Act

The positive excess of the EnEV contributes to the fulfillment of the REHA. To entirely comply that law by a positive excess of the EnEV the primary energy requirement has to be 82.08 kWh/m²a (or lower). The value of the actual situation is 83.31 kWh/m²a in case of the new production building. The difference between the actual and the necessary value is about 1.5 %, so the U-Value of the opaque surface of the NPB has to be reduced by about ΔU = -0,015 W/m²K (in average) to fulfill the REHA by this measure (see Energy Saving Regulation).

Investment appraisal

Table 7: Investment for additional insulation, own design

Surface	Area in m²	Specific costs in €/m²	Total costs in €
Exterior wall	22,051	5.36	118,193
Roof	16,050	3.75	60,187
			178,380

Table 7 summarizes the investment costs (equal to the NPV as no future cash-flows exist).

Confrontation of the options

PV plants and the improvement of the insulation are building-specific measures, whereas the purchase of bio-district heat influences the whole supply area.

PV plants cannot be placed on every construction in the required scale and the improvement of the insulation is only available for effects in a small scale. The purchase of bio-district heat however, represents a long-term solution for the compliance of the laws on the energy performance of buildings for the whole supply area.

Table 8: Comparison of the alternatives, own design

	PV plant	Bio-district heat	Insulation
Availability	depends on building structure	supply area	for all buildings in a limited scale
Affected units	single building	supply area	single building
Energy laws	compliance if available in necessary scale	long-term securing of compliance	applicable in case of a small-scale non-compliance
Investment	442,335 € (case study)	620,200 € (supply area)	178,380 € (case study)
NPV	- 37,913 € (case study)	- 5,866,859 € (supply area)	- 178,380 € (case study)

However, the net present values of the alternatives differ a lot (see Table 8). Whereas the PV plant generates positive cash-flows and has a payback-period of 18 years, the purchase of bio-heat produces costs of almost 6 million € over the project period. The NPV for the improvement of insulation is equal to the initial investment.

VII. CONCLUSION

After all considerations in the frame of this work, the conclusion and recommendation to the energy department of company is, from an economic point of view, to install PV plants on a building if it cannot comply the energy laws. Nevertheless, due to the limits of feasibility of this option in certain cases, the risk of non-compliance should be assessed and weighted up with the option to ensure a long-term compliance by the more expensive connection to the bio-district heat grid. In addition, the investment appraisal is executed using static prices (recent market/supplier price) for gas and electricity. If, as an example, the natural gas price increases in the next years, the purchase of the bio-district heat generates less additional costs or can even produce positive future cash-flows. For a more precise analysis the prognosis of the future development of these prices should be included into the investment appraisal.

To sum up it can be recommended to the company to put further effort into the decision procedure by doing a risk assessment and an investment appraisal considering the future trend of energy prices.

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