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Comparison of Energy Supply Options for Novartis „Campus des Wissens“

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1. Background

Currently Novartis is transforming Werk St. Johann in Basel into “Campus des Wissens”. New buildings will be constructed in the area, which leads to the need of revising the energy supply concept. For some applications the anticipated energy consumption exceeds the goals set up by the local authorities. According to the agreement between Novartis and the authorities the supply of the additional amount of energy needed should be based on technologies that exhibit particularly high environmental standards and are preferably based on renewable energy carriers.

Within Project GaBE (“Ganzheitliche Betrachtung von Energiesystemen”) Paul Scherrer Institut established a framework and the associated databases for the systematic and detailed comparative assessment of energy systems. Elements of this approach have been employed in the present work for the evaluation of suggested options that could be of interest for Novartis.

2. Assessment Scope and Level of Detail

The assessment concerns supply of electricity, heat and cooling. Originally, only the means of supplying energy in excess of the base level were to be addressed. In the course of this project it has been agreed with Novartis that also the base supply from waste incineration plant (KVA), will be covered. It can serve as the reference for the comparisons. Furthermore, the exact amount of energy above the base level is not known as the buildings are still at the design stage.

The current analysis addresses selected energy carriers and technologies considered to be of interest for the Campus. The selection is certainly not exhaustive but is considered sufficiently broad to reflect the spectrum of alternatives of main interest. Additional alternatives could be proposed but also availability of reasonably reliable and consistent data describing system performance was an essential factor when selecting the candidates. Novartis wished that only options that are technically available should be addressed. Detailed analysis of options potentially suitable for consideration in the present study but not covered by previous analysis, was outside of the scope of this work. Specifically for the cooling systems only the alternatives proposed by Novartis were considered. Generally, the overall system solutions analyzed do not include all possible combinations of technologies for heat and power supply. Optimizing the overall configuration would call for detailed specification of the conditions, including the load curves.

The feasibility of implementing the options has not been addressed. For some systems this depends on the local physical conditions, conditions for commercial contracts that need to be negotiated and on practical constraints.

The options of interest are characterized by a number of selected parameters. In some cases average values, in other intervals were used. The precision of the numerical information varies but the level of detail in the characterization of the alternatives is considered adequate for the purpose of the study, i.e. the resolution needs to be good enough to allow for differentiation between these characteristics of the options that are most essential for the evaluation.

The main focus of the evaluation is on environmental features of the options of interest. This is motivated by the objective to identify options that have particularly favourable environmental features. Nevertheless, the cost aspect has been addressed since when choosing between the alternatives that qualify from the environmental point of view the cost component plays a decisive role.

3. Analysis Approach

Methodology

PSI uses a set of criteria and the associated indicators to characterize current and future energy systems and carry out comparative assessment, including relative evaluation of sustainability (Energie-Spiegel Nr. 3, 2000). The environmental assessment is primarily based on Life Cycle Assessment (LCA) which covers direct and indirect emissions as well as other burdens from full energy chains (i.e. apart from power plants or heat sources also up- and down-stream parts of energy chains are included). The external cost assessment may be employed, particularly if location-specific impacts and their monetization are of interest. In the present study only LCA was used since external cost assessment would require significantly extended resources.

Depending on the candidate technologies also risk assessment may be employed to investigate the issue of severe accidents that may occur in the various parts of the chains. Based on the selection of the systems of primary interest for this study their risk features were not considered to be essential.

The results of the environmental and economic evaluation may be aggregated by estimation of total costs, composed of internal (production) costs and external costs. Such an aggregation has not been carried out since external costs were not generated. Another aggregation approach used by PSI is multi-criteria decision analysis (MCDA), which provides a framework that allows the often conflicting evaluation criteria (such as environment versus economy) to be addressed simultaneously. The MCDA approach was not applied in this analysis within the agreed scope but given the interest of stakeholders an extension would be possible.

Analysis Steps

The following analysis steps were employed for electricity and heat supply:

1. Select relevant criteria and indicators for energy carrier/technology comparison.
2. Select preliminary candidate energy carriers/technologies of interest for electricity and heat supply plus reference systems to be used for comparison.
3. Generate comparison matrix with quantitative and qualitative indicators.
4. Screen energy carriers/technologies of highest interest.
5. Compare heat and electricity supply mixes of highest interest and formulate recommendations.

For cooling systems only a subset of the above steps was used since the candidate options were predefined.

Main Evaluation Criteria and Indicators

The main evaluation criteria are shown below. Criteria with quantified indicators are marked in bold style; other criteria are commented in a qualitative manner when making the overall evaluation though in some cases this is based on hard numbers. Some of the indicators are not complete – this applies primarily to cases where specific criterion has low relevance for a particular technology.

Financial Requirements:	**Production cost**
Resources:	Availability/Need of Back-up
	Consumption of energetic and non-energetic resources[1]
Pollutant Emissions:	**SO_x, NO_x, PM10**
	Heavy metals (cadmium used as a representative example)
Global Warming:	**CO_2-equivalents**
Wastes:	**Reststoffdeponie**
	High- and medium- radioactive wastes
Local disturbance:	Noise, visual amenity, impact on ecosystems

This is a subset of criteria used by PSI in full scope evaluation. The reason for the reduced scope is that the options of primary interest are renewable and share some features, which result in similar performance on other criteria. Some of the criteria not directly used here are, however, relevant for the Swiss electricity mix[2] employed here partially for base level supply and partially for the sake of comparison. For more detailed evaluation of the main components of this mix (hydro and nuclear) we refer to a number of PSI publications (e.g. Hirschberg & Voss, 1999; Gantner et al., 2001).

[1] Energetic resources are represented by "Long-term sustainability"; non-energetic resources (such as material consumption) are not explicitly treated but have been considered in the evaluation.

[2] The Swiss electricity supply mix referred to in this paper means production mix. It can be different from the IWB mix.

4. Analysis

Energy Demand and Cases Analysed

According to Novartis the reference energy demand is:

Electricity	80 GWh/a
Heat	90 GWh/a
Cooling	9 GWh/a

It is not fully clear what share of this demand is to be covered by renewable systems. For this reason the following cases have been considered:

1. Electricity supply alternatives (results provided per GWh_e or kWh_e).
2. Heat supply alternatives (results provided per GWh_{th} or kWh_{th}).
3. Electricity and heat supply (results provided for the total demand of electricity and heat needed, based on different combinations of the options of main interest including cogeneration).
4. Cooling options as specified by Novartis.

Candidate Options

Electricity:

Large hydro (run-of-river)

Small hydro

Wind (Swiss or imported from Germany)

Solar Photovoltaic PV (roof panels)

Swiss electricity mix (mainly for comparison)

Hard Coal (for comparison)

Heat:

Heat pumps

Solar collectors

Conventional natural gas and oil boilers (for comparison)

Cogeneration:

Waste incineration (KVA)

Biomass (wood)

Natural gas (for comparison)

Apart from wood also other biomass (as well as different biomass technologies like direct burning or gasification) would be of interest for the evaluation but relevant LCA results are currently not available.

Cooling:

Figure 1 shows the four cooling options considered:

Option 0: Direct cooling using factory water only (rejected as it does not satisfy the comfort requirements)

Option 1: Direct cooling using factory water and drinking water

Option 2: Cooling system with cold water substitution

Option 3: Cooling system employing adsorption cooling aggregate

Comparison of electricity and heat options

Tables 1-9 show the numerical results obtained for the considered options. These are commented below. The LCA-based evaluations originate mainly from Ecoinvent (Frischknecht et al., 1996), established by ETHZ and PSI. The inventories are currently updated to reflect the status of technologies as of year 2000. Publication of updated inventories is expected in the autumn of 2003 (Dones et al., to be published). In the present analysis the values have been partially updated to better represent current well performing technologies, as far as data were available. The numerical results should not be viewed as precise in view of the necessary approximations but they are considered as sufficiently robust to support the conclusions. The costs cited are production costs; the purchase price includes in applicable cases transmission costs and profit margins, and depends on local conditions, contract arrangements, possible subsidies etc.

Electricity:

From the environmental point of view hydro (run-of-river) exhibits the best performance (Table 1). Small hydro is to be preferred. It has slightly higher LCA emissions and other quantifiable burdens including consumption of non-energetic resources but they remain on a very low level in absolute terms. Small hydro normally has better prerequisites for performing more satisfactorily with regard to various types of local disturbances of hydrological-biological nature. In the first place hydro having label “Naturemade Star” is recommended as such products emphasize the optimal environmental performance of hydro. The small hydro plant “Neuewelt” of IWB has received the “Naturemade Star” label. It is assumed that small hydro electricity is available also during the winter; this assumption has not been verified.

Wind is the second best performer after hydro but has more burdens, particularly in terms of consumption of non-energetic resources (materials). The availability of wind energy in Switzerland is very limited and wind requires back-up due to relatively low load factors. Production cost of wind energy in Switzerland are of the same order or higher than for small hydro. Import from Germany, if feasible, would mean lower production costs due to better wind conditions, and consequently also somewhat lower burdens (possible additional burdens related to long-distance transport are not considered as this would depend on details of the available sites).

Solar PV has the weakest environmental performance among the renewables considered and by far the highest production costs. Admittedly, it is possible that the reference technologies considered in the Ecoinvent 1996 have been surpassed by the best PV technologies available today but here the lower range values are used. Furthermore, also use of parameters for future PV analysed by PSI (Dones et. al., 1996), would not change this conclusion.

The Swiss electricity mix is practically CO_2-and pollution-free and thus consistent with some of the major goals of the Swiss energy policy. It is also economically much more competitive than the "new" renewables whose potential is in any case highly limited. Some specific features of the nuclear component (hypothetical severe accidents and radioactive wastes) are not addressed here as they have been analysed in detail in the past (Hirschberg et al., 1998; Hirschberg et al., 2000). Depending on stakeholder perspectives on these issues, the ranking of nuclear energy in sustainability evaluation can vary.

Heat:

Heat pumps have excellent environmental performance as long as the electricity input is reasonably clean (Table 2). Thus, even when good fossil technologies are used for generating the electricity to drive the heat pumps, the resulting emissions of major pollutants are significantly lower than the corresponding emissions from fossil boilers of good standard. When renewable electricity or Swiss electricity mix are used the total heat pump emissions are at a very low level. Use of heat pumps is, however, associated with substantial investment costs and the resulting production costs are significantly higher than those for conventional heating systems (the magnitude of the cost difference depends strongly on the future development of oil and gas prices).

Solar collectors have been included in the comparison as a supplementary option; most probably they can only provide a part of hot water needs and must be combined with other options. They are ecologically sound and their costs have reached acceptable levels.

Cogeneration:

The cogeneration options considered for providing the electricity and heat needed are shown in Tables 3-6. Since in all cases there is still an electricity deficit whose amount varies on a case-by-case basis, it is covered in the calculations by means of the various electricity supply options described in Table 1. In addition, the alternative using heat pumps and various options of electricity supply (both for driving the heat pumps and for supplying electricity) is presented in Table 7. As the supply of heat from KVA is considered a good base case option, the heat pump case covering the full heat demand is not realistic. Rather, heat pumps can be considered to cover the possible excess of heat demand; whether this situation will occur depends on the energy design of the buildings whose relevant properties are not fully known at this stage. For all other options, as long as the electricity gap is covered by non-fossil options the overall emissions to air are driven by the co-generation option used.

The waste incineration plant (KVA) of IWB provides both heat and electricity. The available electricity is highly insufficient for covering the full demand. The KVA emissions are generally much lower than those of gas WKK and even more so in comparison to wood WKK (the reference WKK is a relatively small one; a bigger centralized facility, if available, would exhibit lower emissions as it would employ appropriate abatement equipment). Emissions of heavy metals is an issue for KVA though the magnitude for the IWB KVA is not exactly known; the emissions are in any case below the accepted limits. The emissions used are based on the estimates made in the ExternE Project of the EU (European Commission, 1999). Also economy speaks for KVA since the other alternatives have higher production costs. The electricity deficit can be covered in the first place using the Swiss electricity mix up to the level corresponding to the base case. The excess electricity use can then be covered according to the ranking of recommended electricity supply options described above. The excess heat demand, if any, can be covered by the KVA or by heat pumps driven by non-fossil electricity options.

It is worth mentioning that KVA has two functions, i.e. waste disposal and energy supply. The allocation of emissions and burdens to these two functions is a debated issue. The dominant view is that energy generated by KVA is not its major goal by rather a very useful by-product of handling the wastes. Since the wastes have to be taken care for in any case, the position taken within Ecoinvent2000 (Dones et al., to be published 2003) and also within the available version of the energy inventories (Frischknecht et al., 1996) is that: “All burdens of waste incineration and subsequent processes are allocated to the function “waste disposal”. Generated heat or electrical energy is free of any burden”. This along with the fact that according to the Swiss Federal Office of Energy (BFE) on average about 50% of the wastes burned in the Swiss KVA can be regarded as renewable, supports the view that KVA has favourable environmental performance characteristics.

Biogas from wood gasification or generated by fermentation of agricultural wastes could be considered as an attractive option. No data consistent with those used for the other options are presently available. Furthermore, the availability of such an alternative in Basel is uncertain.

Comparison of cooling options

The cooling systems are needed for air-condition of the offices. Options proposed by Novartis are of much different character (see Figure 1). The basic difference is that Option 1 consumes very small amount of energy (only electricity) while Options 2 and 3 consume about 35 and 4 times more electricity, respectively; in addition, for Option 3 relatively large amount of heat (steam) is needed. In absolute terms the consumption of electricity associated with cooling is, however, rather small, i.e. for Options 2 and 3 it corresponds to about 1.6% and 0.17% of the total electricity consumption envisioned for the Campus. On the other hand, the steam needed for Option 3 corresponds to about 14.8% of the expected heat needs. Option 1 is in terms of investment costs almost 3 times more expensive than Options 2 and 3 but its annual operational costs are 2.6 and 3.2 times lower than those of Option 1, respectively. However, as opposed to Options 2 and 3, Option 1 needs apart from factory water also 120’000 m^3 drinking water in order to assure satisfactory performance of the cooling systems.

The results of calculations shown in Tables 8-10 show that the burdens to the environment are highest for Option 3, followed by Option 2; Option 1 has the lowest burdens. These results are based on uses of the considered environmentally friendly electricity supply options in applicable cases. In Option 3 the steam is assumed to be produced by KVA, which dominates the burdens. In this context we refer to the discussion on the allocation of the burdens caused by KVA, suggesting that they should not be allocated to energy supply. If this perspective is accepted then Option 3 may be considered preferable to Option 2.

On the other hand BUWAL’s view is as follows (BUWAL, 2002):

"Rund 50 Prozent des Abfalls, der in Kehrichtverbrennungsanlagen (KVA) verbrannt wird, besteht aus erneuerbarer Biomasse. Das heisst, dass die Hälfte der KVA-Wärme erneuerbar ist. ... Aus umweltpolitischer Sicht soll Kehricht grundsätzlich vermieden werden. Der trotzdem entstehende Abfall soll nicht auch noch privilegiert behandelt werden, indem man den im Kehricht enthaltenen Anteil von Biomasse subventioniert und damit indirekt eine unerwünschte Förderung der Abfallproduktion vornimmt. Aus diesem Grund gelten im Energienutzungsbeschluss Strom und Wärme aus Kehrichtverbrennung nicht als erneuerbare Energie."

Since the use of the cooling systems is for comfort reasons only (as opposed to the base case supply of heat), the position of BUWAL does not support using KVA for this purpose. Option 2 only involves use of electricity whose generation should be based on the renewable sources according to the priorities established above. Thus, we rank Option 2 higher than Option 3.

As mentioned above option 1 is superior on all criteria used except for the use of drinking water, which is not a fully uncontroversial ecological issue. The arguments supporting the use of drinking water for this purpose are:

- In Switzerland water is a relatively abundant resource.
- Average ground water regeneration rates in Switzerland are very high. Thus, about 30% of the precipitation flows slowly into the ground water (von Gunten, 2000)
- With the exception of Langen Erlen ground water in Kanton Basel-Stadt is available for use for other purposes than drinking (Amt für Umwelt und Energie Kanton Basel-Stadt, 2003). Currently about 20% of the total annual ground water consumed by Kanton Basel-Stadt is used by “Industrie und Gewerbe” (IWB, 2000). Option 1 corresponds to an increase of such uses to about 20.4%.

The arguments against using drinking water are:

- Also in Switzerland it is advisable to pay attention to sustainable consumption of water resources. In densely populated areas the consumption of drinking water is of the same order of magnitude as the regeneration rates.
- Drinking water to be used for cooling purposes will be eventually released into the Rhein river. The drinking water is chemically treated and contains chemicals such as chlorine dioxide (for safety reasons), natriumsilikofluoride (for dental prophylaxis) and other (for protection against corrosion).

Given that the drinking water consumption for the cooling purposes is relatively small, the negative impacts are very limited, the burdens from energy needed are most favourable for this option and the costs are by far the lowest, Option 1 appears to be acceptable. However, a definite ranking can hardly be established. First, it would require the development and investigation of additional criteria, which is beyond the scope of the present study. Second, the overall evaluation of Option 1 against the other cannot be made on exclusively scientific basis since also subjective preferences play a central role. The question is whether a solution with passive cooling and no or significantly reduced consumption of drinking water could be formulated. Such a solution, if feasible, would most probably represent the best compromise. Designing such an option is beyond the expertise of the assessment group at PSI and outside of the scope of this project.

5. Conclusions and Recommendations

Based on comparing the alternatives the main conclusions and recommendations can be summarized as follows:

1. The base supply of heat and electricity for "Campus des Wissens" is environmentally sound when based on KVA and IWB/Swiss electricity mix, as in the past.
2. For the electricity supply in excess of the base case needs, in the first place hydro power having label "Naturemade Star" is recommended (such as the "Neuewelt" plant). This applies also to the electricity needed for the cooling options considered.
3. For the heat supply in excess of the base case, use of heat pumps is recommended, if feasible. The estimates made for heat pumps in this report should be considered as indications. In particular, for the production costs factors such as size, heat source, temperature at the user side, mono- or bivalent operation, capital amortization time etc., are decisive for the realistic evaluation.
4. Use of biogas has not been evaluated in this analysis. Would such an alternative be available in Basel, it could become an attractive cogeneration alternative to be considered.
5. Among the cooling options alternative 2 is preferable to alternative 3. Option 1 has the lowest burdens from energy inputs and the lowest costs and appears to be the most attractive. The associated consumption of drinking water is relatively low and already accepted for industrial uses in Kanton Basel-Stadt; the Swiss average ground water regeneration rates are among the highest. However, the trade-off between economy and energy-related burdens on the one hand and use of drinking water on the other is subject to stakeholder preferences. For this reason, it is recommended to consider whether extending the passive cooling features of this option thus reducing consumption of the drinking water, is feasible (e.g. using evaporation cooling). Such an option would be more robust with regard to the expected differences between various stakeholder views.

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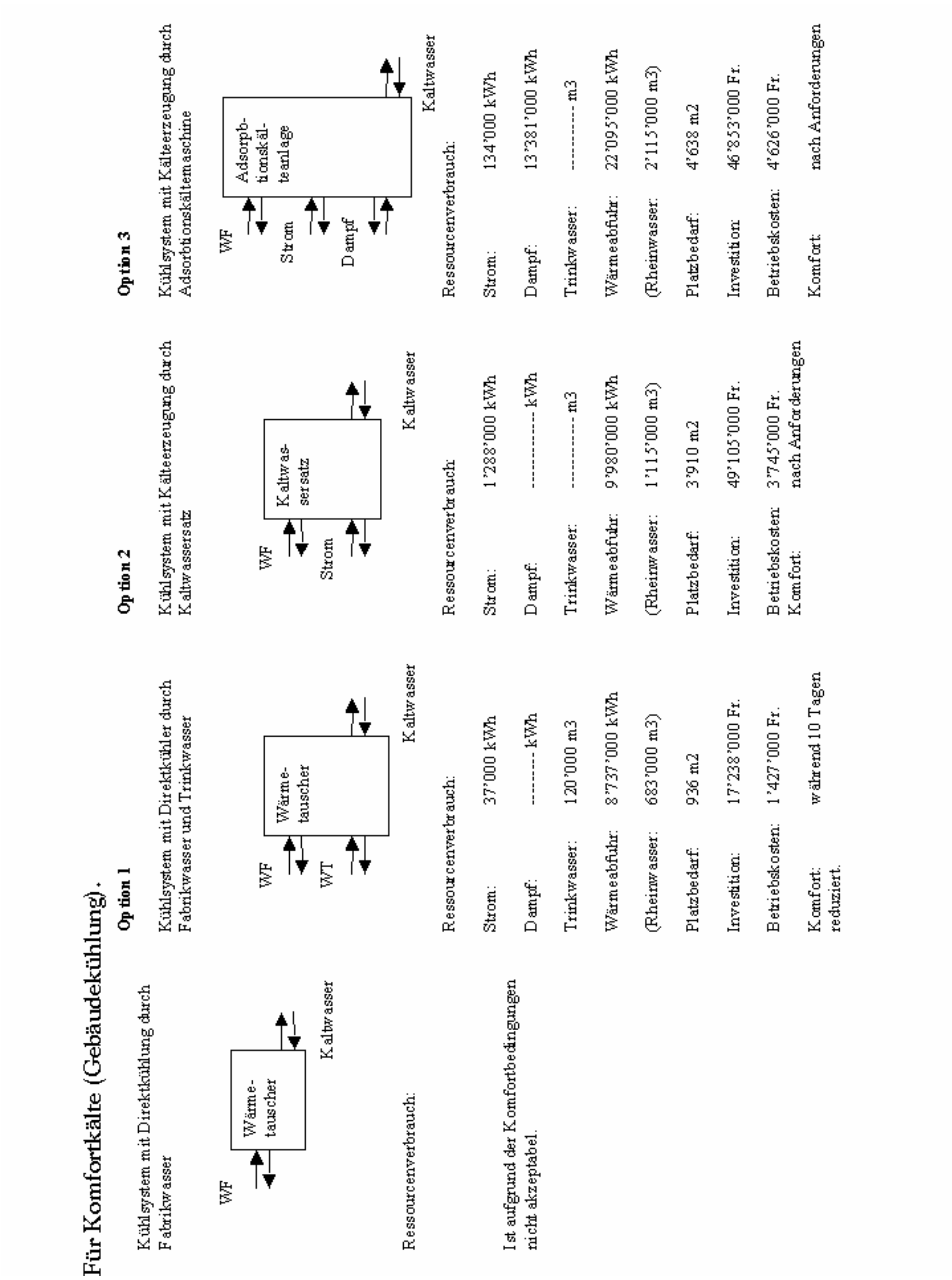
Figure 1: Cooling options that were considered



Für Komfortkälte (Gebäudekühlung).

Kühlsystem mit Direktkühlung durch Fabrikwasser

Ressourcenverbrauch:

Ist aufgrund der Komfortbedingungen nicht akzeptabel.

Option 1

Kühlsystem mit Direktkühler durch Fabrikwasser und Trinkwasser

Ressourcenverbrauch:

Strom:	37'000 kWh
Dampf:	--------- kWh
Trinkwasser:	120'000 m3
Wärmeabfuhr:	8'737'000 kWh
(Rheinwasser:	683'000 m3)
Platzbedarf:	936 m2
Investition:	17'238'000 Fr.
Betriebskosten:	1'427'000 Fr.
Komfort: reduziert.	während 10 Tagen

Option 2

Kühlsystem mit Kälteerzeugung durch Kaltwassersatz

Ressourcenverbrauch:

Strom:	1'288'000 kWh
Dampf:	------------- kWh
Trinkwasser:	------------ m3
Wärmeabfuhr:	9'980'000 kWh
(Rheinwasser:	1'115'000 m3)
Platzbedarf:	3'910 m2
Investition:	49'105'000 Fr.
Betriebskosten:	3'745'000 Fr.
Komfort:	nach Anforderungen

Option 3

Kühlsystem mit Kälteerzeugung durch Adsorbtionskältemaschine

Ressourcenverbrauch:

Strom:	134'000 kWh
Dampf:	13'381'000 kWh
Trinkwasser:	----------- m3
Wärmeabfuhr:	22'095'000 kWh
(Rheinwasser:	2'115'000 m3)
Platzbedarf:	4'638 m2
Investition:	46'853'000 Fr.
Betriebskosten:	4'626'000 Fr.
Komfort:	nach Anforderungen

Table 1 Electricity supply alternatives

Electricity		Large Hydro	Small Hydro	Wind Swiss	PV	Swiss Mix	Hard Coal Imported El
		$/GWh_{el}$	$/GWh_{el}$	$/GWh_{el}$	$/GWh_{el}$	$/GWh_{el}$	$/GWh_{el}$
Financial Requirements: Production Cost	Rp/kWh	8	16	16	100	8	6.3
Resources:							
Availability /Need of Backup		No	Probably not	Yes, if high	Yes, if high	No	No
Long-Term Sustainability		Yes	Yes	Yes	Yes	Yes	No
Pollutant Emissions:							
SO_x	kg	7.6	20.3	70	590	90	920
NO_x	kg	11.7	31.2	25	275	38	1630
PM10	kg	6.8	18.1	35	167	18	1150
Cd for Heavy Metal	g	0.2	0.5	3.5	5.1	0.5	6.5
Global Warming CO_2-eq.	t	4	10.7	12.5	115	20	950
Wastes							
Reststoffdeponie	kg	30	80	513	4000	350	4000
High + Medium Radioactive	kg	0.006	0.02		0.6	4	0.1
Local Disturbance (Noise, Visual Amenity)		Visual, Ecosystem	Negligible	Visual	Negligible	Visual, Ecosystem	Visual, Ecosystem

Table 2 Heat supply alternatives

Heat		Heat Pump	Solar Collectors	Gas	Oil	Wood boiler 1000 kW
		/GWh$_{th}$	/GWh$_{th}$	/GWh$_{th}$	/GWh$_{th}$	/GWh$_{th}$
Financial Requirements: Production Cost	Rp/kWh	25		7.5	7.5	
Resources:						
Availability /Need of Backup		Probably yes	Probably yes	No	No	No
Long-Term Sustainability		Yes	Yes	No	No	Yes
Pollutant Emissions:						
SO_x	kg	130	101	167	450	35
NO_x	kg	58	75	204	330	562
PM10	kg	31	90	18.5	35	256
Cd for Heavy Metal	g	1.2	1.7	0.8	3.4	
Global Warming CO_2-eq.	t	25	30	273	330	10
Wastes:						
Reststoffdeponie	kg	947	1600	997	1580	147

Table 3 WKK options with Swiss Mix for electricity

	Total									
Electricity required	80	GWh/a								
Heat required	90	GWh/a			Rest el.			SUM	SUM	SUM
					WKK Gas	KVA	Biomass	WKK Gas	KVA	Biomass
		WKK Gas	KVA	Biomass	Swiss Mix	Swiss Mix	Swiss Mix	Swiss Mix	Swiss Mix	Swiss Mix
			Basel/IWB	Holz WKK						
Rest electricity required	GWh/a				12	62	70			
Financial Requirements: Production Cost	CHF	5472000	n.a.	n.a.	928000	4960000	5610959	6400000	10432000	11082959
Pollutant Emissions										
SO_x	kg	19260	4414	13650	1044	5580	6312	20304	9994	19963
NO_x	kg	31140	14284	35014	441	2356	2665	31581	16640	37679
PM10	kg	2700	5242	2219	209	1116	1262	2909	6358	3482
Cd for Heavy Metal	g	133	36536	n.a.	6	31	35	139	36567	35
Global Warming CO_2-eq.	t	41508	28364	1310	232	1240	1403	41740	29604	2713
Wastes										
Reststoffdeponie	kg	92700	1283819	15405	4060	21700	24548	96760	1305519	39953

Table 4 WKK options with Large Hydro

	Total									
Electricity required	80 GWh/a									
Heat required	90 GWh/a				Rest el.			SUM	SUM	SUM
					WKK Gas	KVA	Biomass	WKK Gas	KVA	Biomass
		WKK Gas	KVA	Biomass	Large Hydro	Large Hydro	Large Hydro	Large Hydro	Large Hydro	Large Hydro
			Basel/IWB	Holz WKK						
Rest electricity required	GWh/a				12	62	70			
Financial Requirements: Production Cost	CHF	5472000	n.a.	n.a.	928000	4960000	5610959	6400000	10432000	11082959
Pollutant Emissions										
SO_x	kg	19260	4414	13650	88	471	533	19348	4885	14183
NO_x	kg	31140	14284	35014	136	725	821	31276	15009	35834
PM10	kg	2700	5242	2219	79	422	477	2779	5664	2696
Cd for Heavy Metal	g	133	36536	n.a.	2	12	14	136	36548	14
Global Warming CO_2-eq.	t	41508	28364	1310	46	248	281	41554	28612	1591
Wastes										
Reststoffdeponie	kg	92700	1283819	15405	348	1860	2104	93048	1285679	17509

Table 5 WKK options with Swiss Wind

	Total									
Electricity required	80 GWh/a									
Heat required	90 GWh/a				Rest el.			SUM	SUM	SUM
					WKK Gas	KVA	Biomass	WKK Gas	KVA	Biomass
		WKK Gas	KVA	Biomass	Wind Swiss	Wind Swiss	Wind Swiss	Wind Swiss	Wind Swiss	Wind Swiss
			Basel/IWB	Holz WKK						
Rest electricity required	GWh/a				12	62	70			
Financial Requirements: Production Cost	CHF	5472000	n.a.	n.a.	1856000	9920000	11221918	7328000	15392000	16693918
Pollutant Emissions										
SO_x	kg	19260	4414	13650	812	4340	4910	20072	8754	18560
NO_x	kg	31140	14284	35014	290	1550	1753	31430	15834	36767
PM10	kg	2700	5242	2219	406	2170	2455	3106	7412	4674
Cd for Heavy Metal	g	133	36536	n.a.	41	217	245	174	36753	245
Global Warming CO_2-eq.	t	41508	28364	1310	145	775	877	41653	29139	2187
Wastes										
Reststoffdeponie	kg	92700	1283819	15405	5951	31806	35980	98651	1315625	51385

Table 6 WKK options with Hard Coal (Imported Electricity)

	Total									
Electricity required	80 GWh/a									
Heat required	90 GWh/a				Rest el.			SUM	SUM	SUM
					WKK Gas	KVA	Biomass	WKK Gas	KVA	Biomass
		WKK Gas	KVA	Biomass	Hard Coal	Hard Coal	Hard Coal	Hard Coal	Hard Coal	Hard Coal
			Basel/IWB	Holz WKK						
Rest electricity required	GWh/a				12	62	70			
Financial Requirements: Production Cost	CHF	5472000	n.a.	n.a.	730800	3906000	4418630	6202800	9378000	9890630
Pollutant Emissions										
SO_x	kg	19260	4414	13650	10672	57040	64526	29932	61454	78176
NO_x	kg	31140	14284	35014	18908	101060	114323	50048	115344	149337
PM10	kg	2700	5242	2219	13340	71300	80658	16040	76542	82877
Cd for Heavy Metal	g	133	36536	n.a.	75	403	456	209	36939	456
Global Warming CO_2-eq.	t	41508	28364	1310	11020	58900	66630	52528	87264	67940
Wastes										
Reststoffdeponie	kg	92700	1283819	15405	46400	248000	280548	139100	1531819	295953

Table 7 Heat from heat pumps, electricity from different options

	Total	Heat and electricity separately								
Electricity required	80	Heat	Electr	SUM	Electr	SUM	Electr	SUM	Electr	SUM
Heat required	90	Heat Pumps		Heat Pumps		Heat Pumps		Heat Pumps		Heat Pumps
			Swiss Mix	Swiss Mix	Swiss Mix	Swiss Mix	Large Hydro	Large Hydro	Wind Swiss	Wind Swiss
Rest electricity required	GWh/a		80		80		80		80	
Financial Requirements: Production Cost	CHF/a	22500000	6400000	28900000	6400000	28900000	6400000	28900000	12800000	35300000
Pollutant Emissions										
SO_x	kg/a	11700	7200	18900	7200	18900	608	12308	5600	17300
NO_x	kg/a	5220	3040	8260	3040	8260	936	6156	2000	7220
PM10	kg/a	2790	1440	4230	1440	4230	544	3334	2800	5590
Cd for Heavy Metal	g/a	108	40	148	40	148	16	124	280	388
Global Warming CO_2-eq.	t/a	2250	1600	3850	1600	3850	320	2570	1000	3250
Wastes										
Reststoffdeponie	kg/a	85230	28000	113230	28000	113230	2400	87630	41040	126270

Table 8 Electricity for cooling, option 1

Kühlsystem mit Direktkühlung durch Fabrikwasser und Trinkwasser

Steam required	GW_{th}/a	0					
Electricity required	Gwh_{el}/a	0.037					
Total requirement as electricity	Gwh_{el}/a	0.037					
		Large Hydro	Small Hydro	Wind Swiss	PV	Swiss Mix	Hard Coal Imported Electr.
		/a	/a	/a	/a	/a	/a
Financial Requirements: Production Cost	CHF	2960	5920	5920	37000	2960	2331
Resources							
Availability /Need of Backup Potential		No	Probably not	Yes, if high	Yes, if high	No	No
Long-Term Sustainability		Yes	Yes	Yes	Yes	Yes	No
Pollutant Emissions							
SO_x	kg	0.3	0.7	2.6	21.8	3.3	34.0
NO_x	kg	0.4	1.2	0.9	10.2	1.4	60.3
PM10	kg	0.3	0.7	1.3	6.2	0.7	42.6
Cd for Heavy Metal	g	0.007	0.02	0.1	0.2	0.02	0.2
Global Warming CO_2-eq.	t	0.1	0.4	0.5	4.3	0.7	35
Wastes							
Reststoffdeponie	kg	1	3	19	148	13	148
High + Medium Radioactive	kg	0.0002	0.0006	n.a.	0.02	0.15	0.004

Table 9 Electricity for cooling, option 2

Kühlsystem mit Kälteerzeugung durch Kaltwassersatz							
Steam required	GW_{th}/a						
Electricity required	Gwh_{el}/a	1.288					
Total requirement as electricity	Gwh_{el}/a	1.288					
		Large Hydro	Small Hydro	Wind Swiss	PV	Swiss Mix	Hard Coal Imported Electr.
		/a	/a	/a	/a	/a	/a
Financial Requirements: Production Cost	CHF	103040	206080	206080	1288000	103040	81144
Resources:							
Availability /Need of Backup Potential		No	Probably not	Yes, if high	Yes, if high	No	No
Long-Term Sustainability		Yes	Yes	Yes	Yes	Yes	No
Pollutant Emissions							
SO_x	kg	9.7888	26.1034667	90.16	759.92	115.92	1184.96
NO_x	kg	15.0696	40.1856	32.2	354.2	48.944	2099.44
PM10	kg	8.7584	23.3557333	45.08	215.096	23.184	1481.2
Cd for Heavy Metal	g	0.2576	0.68693333	4.508	6.5688	0.644	8.372
Global Warming CO_2-eq.	t	5.152	13.7386667	16.1	148.12	25.76	1223.6
Wastes							
Reststoffdeponie	kg	38.64	103.04	660.744	5152	450.8	5152
High + Medium Radioactive	kg	0.007728	0.020608	0	0.7728	5.152	0.1288

Table 10 Electricity and steam for cooling, option 3

Kühlsystem mit Kälteerzeugung durch Adsorbtionskältemaschine

Steam required	GW_{th}/a	13.381					
Electricity required	Gwh_{el}/a	0.134					
		KVA + Large Hydro /a	KVA + Small Hydro /a	KVA + Wind Swiss /a	KVA + PV /a	KVA + Swiss Mix /a	KVA + Hard Coal /a
Financial Requirements: Production Cost	CHF	1121343	1132063	1132063	1244623	1121343	1119065
Resources:							
Availability /Need of Backup Potential		No	Probably not	Yes, if high	Yes, if high	No	No
Long-Term Sustainability		Yes	Yes	Yes	Yes	Yes	No
Pollutant Emissions							
SO_x	kg	671	673	679	749	682	793
NO_x	kg	2169	2172	2171	2205	2173	2386
PM10	kg	797	798	800	818	798	950
Cd for Heavy Metal	g	5545	5545	5545	5546	5545	5546
Global Warming CO_2-eq.	t	4305	4306	4306	4320	4307	4432
Wastes							
Reststoffdeponie	kg	194845	194852	194910	195377	194888	195377
High + Medium Radioactive	kg	0.0008	0.0021	n.a.	0.08	0.54	0.01