Economic system analysis of anergy networks using the example of the Smart Anergy Quarter in Baden

Extended version of the technical final report of the research project SANBA[1] covering economic aspects

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1. Introduction

In the last few years anergy networks, water-based heating respectively cooling networks which manage the energy transport approximately to surrounding temperature have been more often discussed [3, 4, 7, 8] and demonstrated [1, 5] as future-oriented systems for a sustainable supply of heating and cooling services. The advantages of anergy networks are diverse and vary from extremely low-loss energy respectively anergy transport to corresponding networks, the possible benefit of for example industrial heat loss with low temperature level, the possible heating and cooling storage in geothermal probe storages with great capacity to load compensation between heating and cooling loads within the network and the supply of virtually “free“ services as “Free Cooling“.

In Switzerland already realised pilot and demonstration plants are to be found increasingly. Examples are the anergy network Naters (room heating with heat source groundwater), the Genève lac nations project (office building cooling with water of the lake Geneva) or the ETH Zurich, Hönggerberg (major project with several geothermal probe fields and dynamic development potential), the Suurstoffi area in Rich/Rotkreuz (zero-emission-project with geothermal probe fields, PV and car-free mobility concept) [5, 6], or the family home cooperative Zurich (geothermal probe fields). Research and progress reports mostly refer to aspects of system technology and operational management in detail. Usually empirically based information about economic figures as specific heating and cooling production costs, payback periods etc. are not publicly available.

As strongest economic constraint Gautschi [1] mentions the competition with fossil energy carriers especially natural gas and the high investment costs of the plants in particular the costs of the installation of the anergy network as well as the geothermal probe fields. The same author names the intersection of the cost comparison method between the option heating with fuel / cooling with electricity and the option heating and cooling with anergy network and geothermal probe fields with 12 years for a +3 %/a energy price scenario. For the option natural gas respectively with an increasing calculation interest rate this period clearly lengthens.

Based on the experiences of the existing pilot and demonstration plants the economically feasible system analysis in the project SANBA is made on the basis of two different approaches. A top-down approach on the basis of network figures and a micro-data-based bottom-up approach on the basis of the capital value method are compared and also complemented.

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2. Project concept

In the project SANBA a specific anergy network is investigated by means of an area in the city of Baden near Vienna. The investigated area are the Martinek barracks on the southern outskirts of Baden near Vienna, not used by the Austrian military since 2014 and the dairy NÖM AG in immediate neighbourhood (***figure 1***). The barracks area has a total area of approximately 40 ha and can be considered as an attractive city expansion area. A monument protected building stock is situated in the barracks area which was constructed in the 1930s (***figure 2***). The whole building group is protected which has a great influence on renovation options of existing buildings, on the possible installations of technologies for the use of renewable energy as photovoltaics or solarthermics and on the possibilities of a redensification through new buildings on the available open space.

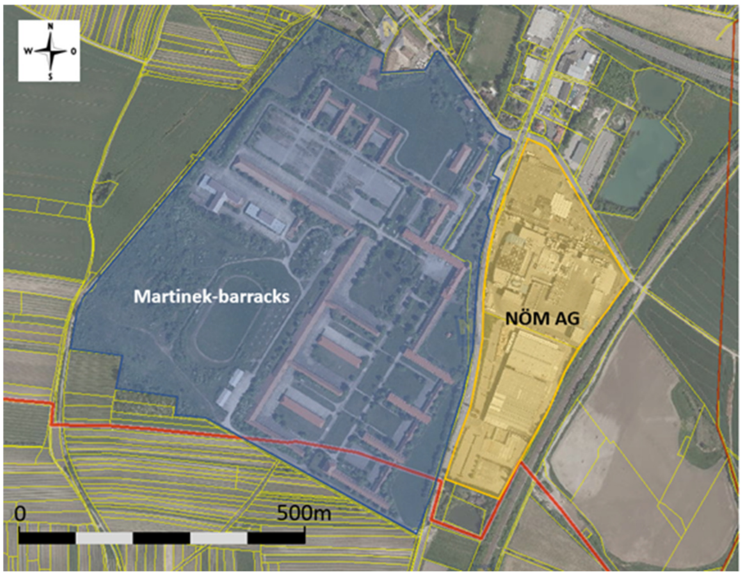

Figure 1*: The investigated area consisting of the Martinek barracks in Baden close to Vienna as well as the company grounds of the NÖM AG: Source orthophoto: NÖ Webgisatlas, atlas.noe.gv.at.*

As basis for the plans and calculations of the SANBA project three specific development scenarios were defined. These scenarios range from the scenario “MINI“ (mere renovation and use of the monument protected existing building without construction of new buildings) to the scenario “MIDI“ (additional integration of slightly compacted new buildings) to the scenario “MAXI“ (compacted building development of the area with mixed use in terms of habitation, business and education). The low temperature heating source is in all three scenarios the neighbouring dairy NÖM AG whereas principally different production processes exist where heat loss which cannot be further used within the company is available. The disposal of the heat loss also causes costs within the company through for example the operation of recooling systems.

***Figure 2**: Views of the monument protected existing buildings in the area of the Martinek barracks in Baden near Vienna. Pictures: Peter Biermayr.*

The essential system components of the research object are schematically illustrated in ***figure 3*** respectively for an operation in winter and summer. The essential components are residential buildings, service buildings, geothermal probe storage, water-based technical storage, the central heat loss source, decentralised heat pumps as well as a 2-piped anergy network. Typical temperatures of the heating flow range in winter from 7 to 12°C and in summer from 12 to 22°C. The respective temperature difference to the return amounts to approximately 4 to 5K.

The basic data for the modelling and system analysis in the project SANBA have been empirically collected in regard to the existing buildings, the qualities of a central heating source and in regard to the hydrogeological and thermotechnical qualities of the underground. In January 2020 in the company grounds of the NÖM AG an exploratory drilling of -150 metres was drilled and expanded as experimental probe. The results confirm the suitability of the underground for the planned heating and cooling storage.

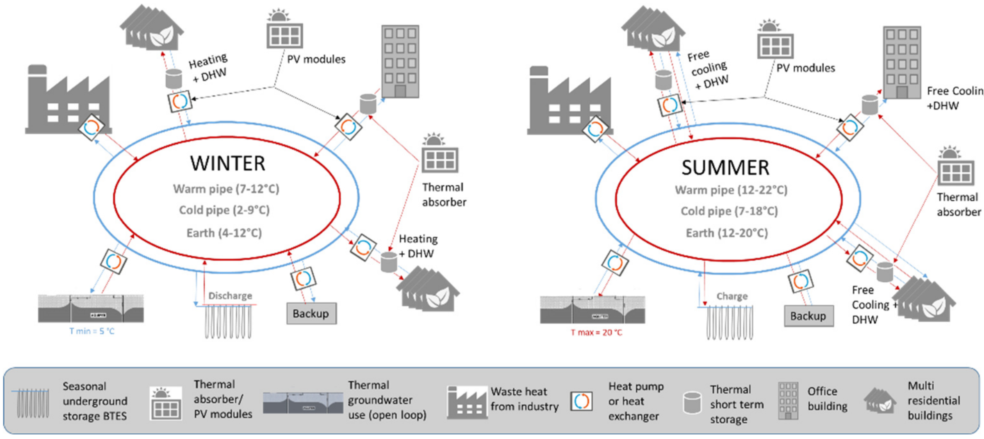

***Figure 3**: Scheme of the SANBA-model system for summer and winter operation*

3. Top-down evaluation approach through network figures

As handy framework condition for a profitable operation of anergy networks Gautschi [1] indicates a density of thermal energy of 3 MWh/(a*m_{route}) for predominant heat use respectively a by 30 % or 50 % lower value with combined heat and cooling use. These figures have been clearly surpassed by the above quoted projects ETH Zurich with 6 MWh/(a*m_{route}) heating usage plus 5 MWh/(a*m_{route}) direct cooling and the family home cooperatives Zurich with

5 MWh/(a*m_{route}) heat supply plus 2,5 MWh/(a*m_{route}) direct cooling whereby these projects may be classified as potentially profitable in regard to the figures of a top-down approach.

Further starting-points for an economic system analysis in the project SANBA are provided by the already concluded research projects GEOSOL [2] and DEGENT-NET [3] whereby in project [3] findings could already be gained within the frame of specific case examples in Vienna and Salzburg.

In regard to the classical high temperature heating networks as is the case with urban district heating or biomass local heat supply, for a rapid evaluation of the economic feasibility figures are commonly used for the specific power density and the specific work density of the network. The minimal densities typically are 1 kW/m_{route} respectively 1,5 MWh/(a*m_{route}) whereas the actual requirements always have to be defined project specifically on the basis of definite planning documents.

Now the displayed figures already reveal a strategic problem of anergy network projects: On the one hand, planners will aim at highly efficient building structures within the frame of renovations and new building projects in order to allow for an energy efficiency in the total system which is as high as possible (low energy figures of the building plus low temperature heat distribution system).

On the other hand, a certain energy turnover is necessary for an economic operation of the anergy network. However, in this respect great economic opportunities are in the additional cooling supply for the cooling of buildings, in the dense structures of new buildings, in the integration of partially energetically restorable buildings with a high heat demand (for instance monument protection), as well as in the application of suitable business models.

The network figures for the three evaluated SANBA-scenarios are summarized in ***table 1***. If you take the above documented framework conditions for an economically successful operation of the system into account there is few hope for the scenario MINI whereas the scenarios MIDI and MAXI show promising figures.

Table 1*: Network figures for the three SANBA-scenarios*

Figures in the SANBA-scenarios	MINI	MIDI	MAXI
Density of thermal energy [MWh_{th}/(a*m_{route})]	1,6	4,9	5,4
Density of thermal power [kW_{th}/m_{route}]	0,8	1,7	2,1

The calculation of the network figures can already be made in an early project phase after establishing the network topology and determining the heating and cooling loads respectively the annual useful energy demand for heating and cooling of buildings. However, this top-down approach may rightly be criticized as “vague“ because of the relatively low information depth. It is nevertheless suitable and empirically sufficiently verified to be used as a method for a rapid evaluation of rough system designs.

4. Bottom-up assessment approach on the basis of the capital value method

A detailed economic system analysis was accomplished in SANBA on the basis of the classical capital value method. The definition and investigation of all cost data including the consideration of learning and scaling effects caused a noticeable effort which may be reduced in practice through aggregation of components and a corresponding tender of system boundaries. The system boundaries have been defined for the calculation with technical limits of the thermal energy system.

However, the purely formally given accuracy of the method is put into perspective through a great number of assumptions which have to be made for the calculations. Here, the uncertainty rests with long-term projects with low discounting especially in the area of divergent developments of deposits and payments (compare electricity price prediction vs. development of heating and cooling prices) respectively likewise in the area of re-investments. In the course of the system analysis the economic robustness of the system may indeed be tested through a variation of essential and critical parameters but the uncertainties which arise due to the long period of calculation cannot be eliminated in doing so. Anyhow, this circumstance is not due to the innovative energy system in SANBA but is rather a general property of projects with lots of investments with long operating life.

In order to illustrate specific results of the profitability calculation which are comparable outside the scenarios the documented assumptions in ***table 2*** have been made for further illustrations.

Table 2*: Assumptions and basic parameter values for the following presentation of results*

Adequate target rate: 3.0 % (variable)
Rising prices (inflation): 1.5 % (general, unspecific)
Electricity price: 100 €/MWh (mere energy price, no fixed and power components; variable)
Reference date t_0: year after completion = full use
Building phase (planning, construction): max. 4 a (scenario MAXI)
Operational phase: 40 a (passive components), 20 a (active components)
Heat price (heating): 60 €/MWh (mere energy price)
Heat price (process water): 80 €/MWh (mere energy price)
Cooling price (Room cooling): 100 €/MWh (mere energy price)
Anergy price (Heat loss): 1 €/MWh (mere energy price)
No consideration of subsidies!

Taking into account the scenario specific micro-cost data for planning, investments, operation, renovation, re-investments and the corresponding payments the following illustrated results arise.

Figure 4 shows an absolute and relative comparison of the costs in the three investigated scenarios, divided into the essential system components. The cost structure shows that with an increasing project size the costs portion of the geothermal probe storage equally increases while the costs portion for “miscellaneous“ (planning services, obligatory industrial management, maintenance contract for energy centres, operating expenses for anergy) decreases.

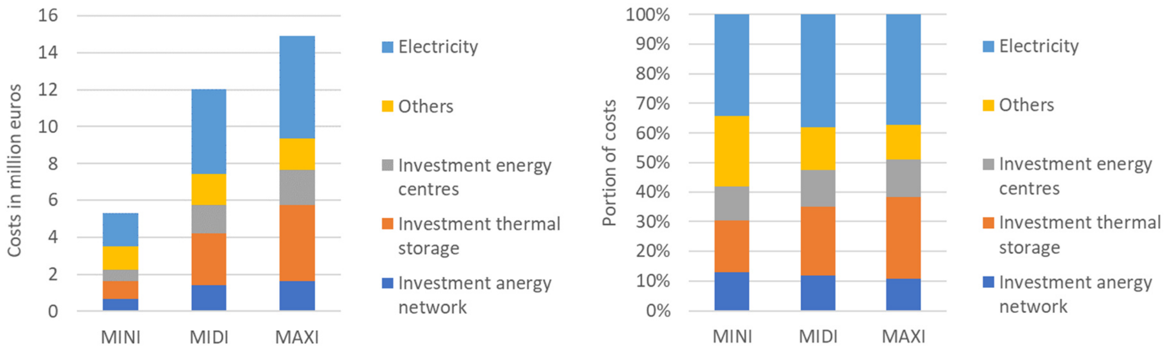

Figure 4*: Comparison of the absolute and relative costs of the investigated SANBA scenarios.*

In ***Figure 5*** the discounted flowing of the deposits and payments for the scenarios MINI and MAXI are illustrated. It becomes apparent that although there are similar relations in the operation phase between deposits and payments this is not the case in regard to the relation between investments and payments. As a result, this imbalance leads to a critical overall economy of the MINI scenario.

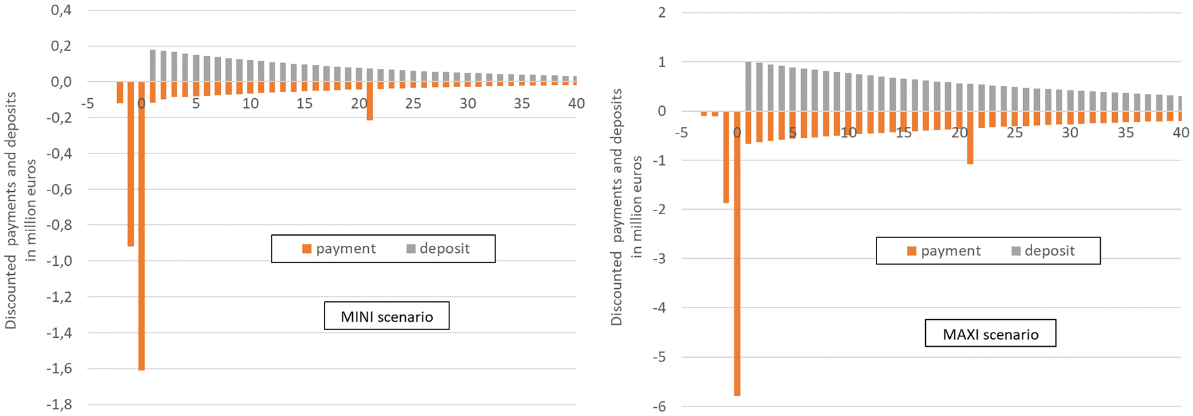

Figure 5*: Dynamic development of the deposits and payments in the scenarios MINI and MAXI over the total project duration.*

Figure 6 shows the capital values of the various scenarios dependent on calculation interest rate (abscissa) and electricity price (parameters of the family of curves). A positive capital value stands for an economically successful constellation under the respective circumstances while a negative capital value stands for a corresponding economic loss.

Consequently, in the MINI scenario there exists only a very small solution space for parameter constellations that make an economically successful project possible. Appropriate solutions would require a calculation interest rate of maximally 2.3 % (corresponds to the maximal internal interest rate) and a maximal electricity price of about 80 €/MWh (mere energy price!). The level of the calculation interest rate (for instance non-profit housing) may possibly be argued but not the required electricity price. If the scenario MINI should be realised in spite of the bad economic starting point, high subsidies have to be granted – possibly as not refundable investment grant.

In the MIDI and MAXI scenario, the economic situation of the energy system is completely different. In these scenarios positive capital values can be achieved under the assumption of realistically feasible parameters. The solution space for economically successful constellations is rather big in these two scenarios which also creates a free space for attractive business models for possible network operators, anergy suppliers or contracting-vendors.

These relations are also displayed in ***figure 7*** where the internal interest rate in dependency of the electricity price is illustrated for the three scenarios. In each case the area under the scenario-specific curve may be considered as solution space for economically successful parameter constellations. The MINI scenario displays - as explained above – a small and not realistically feasible area whereas the MAXI scenario offers the greatest scope. Consequently, the MAXI scenario is the economically most robust system design whereas you need to emphasize that the statements exclusively relate to the investigated thermal energy system of the quarters.

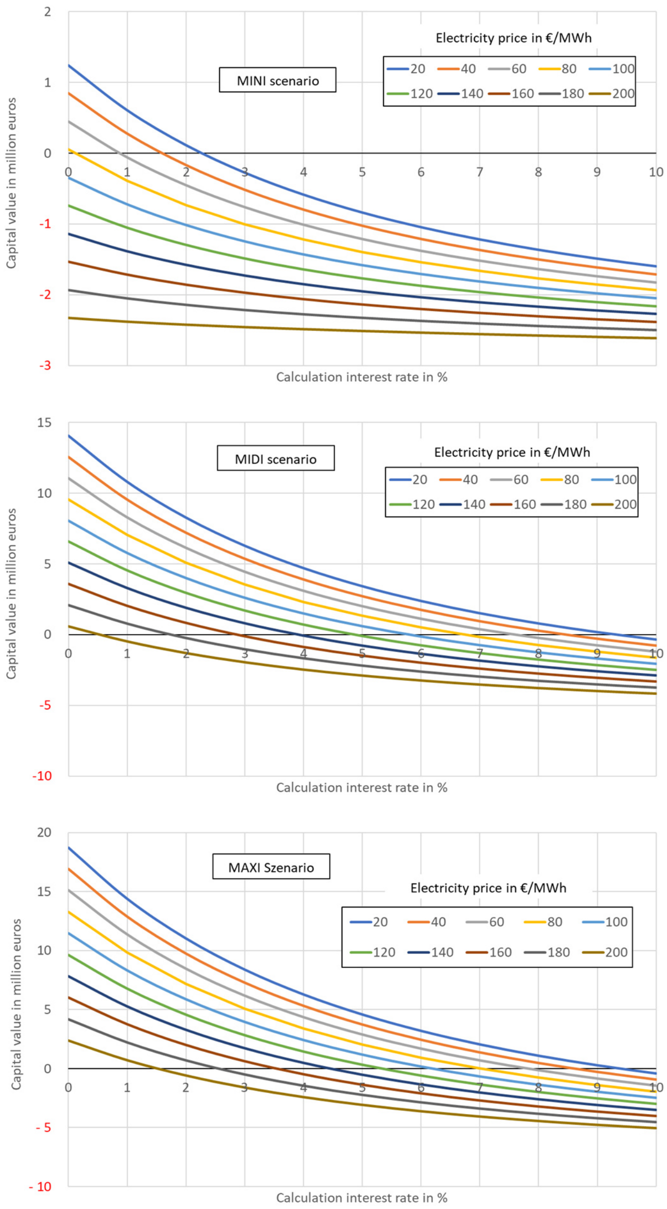

***Figure 6**: Capital values depending on the electricity price and the calculation interest rate for the investigated scenarios.*

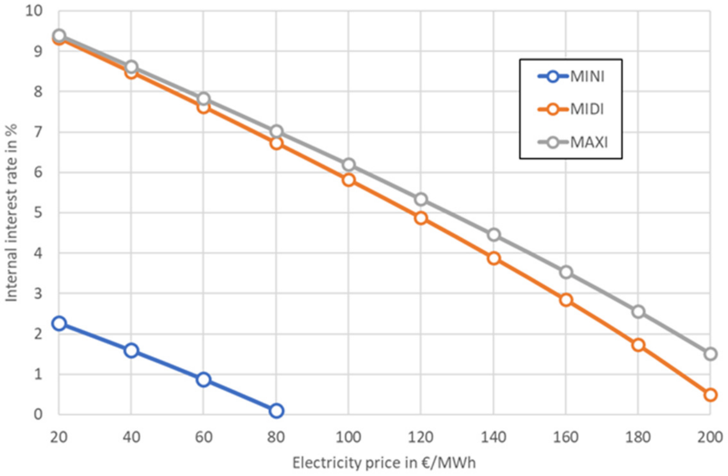

***Figure 7**: Internal interest rate depending on the electricity price.*

5. Further qualitative aspects

Benefits of the grid feed

The heat emission of a grid feed (typically of a business enterprise or an industrial plant) into the anergy network has to have a calculable benefit without process technical risks.

The attainable benefit also depends on the particular point in time when such a project is realized. If the potential grid feed is an established business the mobilizable short-term use is often reduced to a reduction for instance of the operating power of the back cooling.

On the long term respectively with a simultaneous creation of an anergy network and the installations of the grid feed appropriate parts of installations of the grid feed may be economised.

However, in such a case the anergy network operator will have to give a guarantee for a minimum anergy consumption where obligatory agreements are made concerning the load profile and the temperature bandwidths of heating flow and return. Furthermore, in the investigated scenarios MIDI and MAXI a moderate feed-in tariff for the grid feed is also presentable whereas these earnings have lesser importance in comparison to other benefits.

Technical frame of the grid feed

In the course of the empirical surveys in the SANBA project it became apparent that the use of heat loss of cooling plants (for instance back cooling of refrigerating machines) is process technically significantly easier than the use of heat loss of sewage even if it has an attractive temperature level. The background is the temperature dependency of the dissolving power of the sewage and the tendency of precipitation of dissolved constituents during the cooling down. However, at this an intervention in existing plants is by far more difficult and cost intensive than a simultaneous planning and creation of an anergy network and operational plants. As a rule, appropriate sewage heat exchangers have to be provided with cleaning equipment to guarantee a continuous transmission power. The specific costs of such heat exchange installations are significantly higher than of heat exchangers which can for instance be implemented in water-based or brine-based recooling systems.

Investment costs for the anergy network

Calculations of the SANBA-project partner TU Vienna have shown that in case of an underground installation following the company standards of the pipe producer of non-insulated PE 100 PN 10 plastic pipes for the planned 2-piped anergy network (DN 160, wall thickness 9.5 mm) the short loss of heat between hot pipes and cold pipes on the one hand and the heat loss towards the surface of the earth on the other hand amount to below 1 % in comparison to the convectively transferred energy via the pipe. An of any kind whatsoever thermal insulation of the anergy network pipes exceeding the standard wall thickness of the material of the pipes and the bedding of the pipes in sand following the company standards is thus neither thermodynamically reasonable nor economically feasible.

A part from the material costs of the pipelines the laying expense has a great influence on the installation costs of the anergy network. Essential aspects are here the degree of freedom for the choice of the transmission route for a minimal route length (limitations through existing buildings, already used infrastructure routes, traffic routes etc.) as well as the working conditions for the installation ("green meadow" versus inner-city). In this regard, in the case of the SANBA project there are mixed conditions whereas within the area of the barracks there are favourable conditions however, the connection of the dairy factory NÖM AG causes greater efforts (installation underneath sealed areas, crossing of a main road).

The requirements of the pressure resistance of the used plastic pipes are also a further cost factor. The requirements of the pressure resistance of the pipes result mainly from the topology of the anergy network whereby the pipe producers typically offer the standard classes PN 6, PN 10, PN 16 and PN 25. In the case of the SANBA project the pressure class PN 10 is planned as in spite of the great transmission route there is not any significant height difference.

The scale effects in regard to the used pipe diameter are very moderately marked and are negligible from DN 110. The background is that with constant pressure resistance with increasing nominal pipe diameter the wall thickness of the pipes also rises linearly which subsequently lead to almost constant service specific material costs of the various pipe diameters. As a result, the power specific price depends only on the temperature spreading between hot pipes and cold pipes, see ***figure 8***.

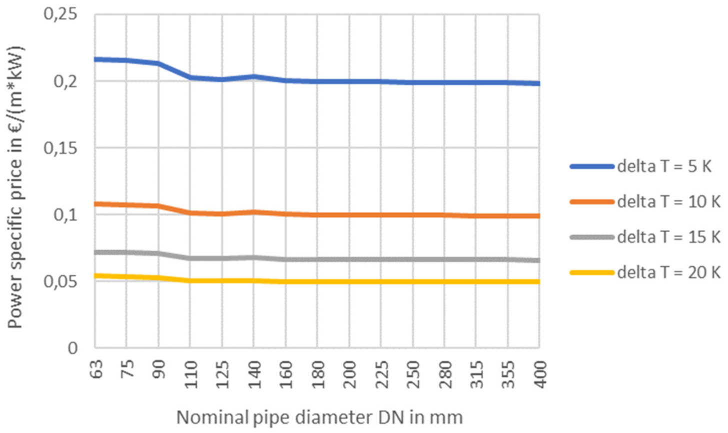

Figure 8*: Service specific prices (excl. VAT) for various pipe diameters depending on the temperature spreading. Respectively for PE 100 PN10 SDR 17, 12 m off-the-peg, excl. closures etc.*

The specific prices of rolled goods which are available in piece lengths of 100 m to maximum DN 160 are approximately 25 % higher than those of the off-the-peg goods. Through the reduction of the shaped pieces and the production effort for the welding etc. the use of rolled goods in sparsely structured network sections is economically feasible.

Scale effects in the energy centres

The absolute size of the anergy network planned in the SANBA project requires numerous energy centres which are the interface to the decentralized energy systems of the buildings or the building sections. The most essential component is either one or more heat pumps. The specific net prices of brine/water heat pump units dependent on the thermal nominal capacity per unit are illustrated in ***figure 9***. On the basis of the collected data, it can be presumed that a splitting up of the necessary power >40 kW per unit is a cost-efficient approach. Similar conditions can be observed with decentralized, water-based heat pumps whereby the limit of sinking prices per storage capacity is reached between 1000 to 2000 litres of storage capacity.

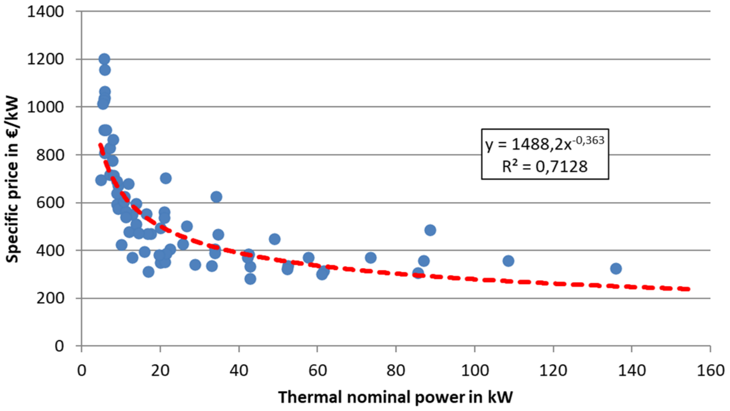

***Figure 9**: Power specific net price of brine/water heat pump units depending on the thermal nominal power.*

Regarding the costs of maintenance and operations of technical components, the costs of appropriate maintenance contracts respectively the contractual prolongation of warranty periods are part of the profitability calculation which reduces the cost risk of potential investors or operators.

The influence of learning effects

The technical realisation of the energy system planned in the SANBA project is feasible with established, on the market available, technical components. The essential components are here geothermal probes, heat pumps, pipe lines, heat exchanger, water-based thermal storage systems as well as pumps and control systems. From the actual moment of planning to the potential moment of realisation no significant economic learning effects can be expected with all these components which might influence the statements regarding the profitability of the system. The situation is similar with the moment of re-investment during the 40-year period under observation of the dynamic observation of profitability. As one cannot expect any significant technical learning effects like efficiency increase or reduced space requirements of components in the named key areas up to the moment of a potential realisation, any influence on profitability of the project is not expected from this part.

Failure reserve and redundancy

In the project SANBA strategies how to deal with system failures were equally discussed. Here scenarios are of particular interest which enlighten a short-term up to permanent failure of the industrial waste heat source at various load conditions of the anergy network. The time periods of the failure are hereby classified as hours, days, weeks and months up to years. Failures in the scale of hours up to days can be managed in heavy-load periods with the help of the system inertia and the performance of the geothermal energy storage. For longer failures lasting several weeks a network interface for the feeding of heat with a mobile container heating plant is provided at first and all the necessary structural measures for a rapid delivery and installation of such a heating plant are taken. Here the investment costs are very low (storage area, driveway, network interface). For the very unlikely case of a long-term or permanent failure of the heat source additional measures for the permanent construction of an air/water large heat pump installation are taken. For the given power requirement in SANBA a storage space the size of a 40-foot container including driveway is necessary. Moreover, the electrical power requirement, possible sound emissions etc. have to be taken into account during the planning. The construction and start-up of a suitable large heat pump installation with appropriately prepared infrastructure requires 4 to 8 weeks according to the producer.

Alternative concepts for the creation of a failure reserve respectively a redundancy in regard to the waste heat source as for example the prophylactic creation of a district heating or a natural gas connection have been investigated in the already quoted project DEGENT-NET [3]. Here it became apparent that the costs of appropriate connections respectively the power provision through the energy supplier causes high costs which have to be priced into the heat production costs of the system. This significantly increases the specific heat costs. The above illustrated solution equally covers all the failure scenarios and only causes marginal costs in the course of a project realisation.

Cooling of buildings

A strong point of the investigated anergy network in the project SANBA is the supply of coldness for the cooling of buildings. Basically, this coldness can be supplied as “Free Cooling“ through the existing geothermal energy storage as the summer temperatures in the cold pipe of the anergy network are suitable for the cooling of buildings. If appropriate facilities for the distribution of the coldness are created in the buildings or the existing heat distribution systems are suitable for distributing the coldness, the cooling of the building does not cause any further costs on the surface apart from the electric driving energy of possible pumps. However, in the course of a systemic analysis costs like the geothermal energy storage have to be included in the provisioning of coldness and a suitable heat and coldness rate has to be defined. Concerning this matter, it has already been shown in the project DEGENT-NET [3] that missing paragraphs or missing rating of coldness in anergy networks result in non-competitive heat prices which is also already expressed in the above quoted figures for the anergy network of Gautschi [1].

Cost structure of anergy networks

Systems with anergy networks are very investment intensive. That is the main part of the relevant life cycle costs arises during the construction of the system. When comparing such systems with operating costs intensive systems as for example a heat supply based on natural gas including provisioning of coldness via compression cooling units the height of the chosen calculated interest rate has a great influence on the result of the comparison (for instance following the hereby used net present value method). Consequently, for an equally fair as well as serious comparison of systems a sensitivity analysis – at least regarding the calculation of the interest rate is indispensable. Further variations should also be conducted in regard to the underlying energy price scenarios.

In light of the national and international climate- and energy targets an evaluation of the avoided greenhouse-gas-emissions also has to take place in the course of the system comparison. This can either be taken care of in a separate emissions balance or it may be implemented in the economic evaluation via costs of CO_2-emissions. In the second case one has to critically mention that predictions in regard to CO_2-prices over a long service life of for instance 40 years are not reasonably feasible and a discounting of monetary CO_2 savings in the course of a dynamic profitability calculation do not really make sense.

6. Summary and Conclusiones

The identified economic success factors in the SANBA project for heating and cooling supply on the basis of anergy networks are:

- The determination of figures for the density of thermal power and thermal energy creates the possible assessment of the profitability in an early planning phase for anergy networks – as well as conventional heating networks.
- The economic analysis with figures and the capital value method show a good convergence of results.
- The heat output of a feed-in (for example industrial plant) to the anergy network has to have a calculable benefit for the feed-in without process technical risk for the key business.
- From the point of view of the feed-in the heat consumption through the anergy network has to be reliable and continuous.
- Process technically the benefit of heat loss from cooling systems is by far easier than the benefit of heat loss from waste water (dissolving power, precipitation).
- The investment costs for the anergy network have to be minimized. As a rule, the use of non-insulated, underground plastic tubes is economically as well as thermodynamically reasonable.
- For the sizing of the energy centres and their components you need to take care of the optimal benefit of scale effects.
- Economic learning curves concerning the system components will hardly influence the profitability of the anergy networks in the following decades.
- Investment costs or contract costs with an external heat supplier for a redundant heating source have to be minimized. However, structural arrangements for the short-term, medium-term and long-term failure of the central heating source have to be made.
- Free cooling is not free of cost. The users have to be charged for the cooling supply in the interest of the overall economy.
- Anergy networks have high investment costs. When comparing these systems to heating and cooling supply systems with mostly operating costs the calculation interest rate has a great influence on the result.
- A comparison of anergy networks with energy systems for the use of fossil energy is not reasonable because of the national, international and global targets for the upcoming decades as fossil energy is no longer an option.

In the concrete SANBA project economically attractive and robust scenarios have been identified. These solution approaches enable the integration of the monument protected existing buildings into a sustainable energy system. The system benefits from industrial low temperature heat loss in an anergy network with geothermal heat storage. The investigated location is especially suitable for the realisation of an internationally remarkable pilot- and demonstration plant.

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