Business Opportunities in Power Supply with Gas Engines in the Health Sector

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Summary

In the research, we have developed an operational concept based on new energy generation devices, which, in addition to providing heat and electricity, guarantees uninterrupted supply locally and the sale of system services off-site. Based on international experience in the sector, the overall business concept needs to be developed for successful pilot projects. The trends in the technical-economic and regulatory environment examined show that the direction of change, with uncertain outcomes today, is unanimous: they all support the market penetration and the continued profitability of small-scale power plant devices suitable for secondary regulation. An important task is to identify unique elements in the value propositions. The aim of the research is to identify which of the factors such as realized price differential, heat-side revenues, generation utilization, optimized plant operation, scaling, etc. have an impact on the investment, operation, as well as the overall business model and profitability, and to what extent.

Keywords: generation optimization, ESCO, gas engine, operation, UPS

JEL codes: O0, O1, O3

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Nowadays the main question is not whether or not we should select renewable or sustainable energy supply solutions instead of the traditional solutions, but rather which technology and business model from the environment- and climate-friendly and energy efficient solutions would suit the area of usage and the limitations of investments best (Zheng et al. 2017). The guidelines and the objectives of the EU and relevant national policies all support this.

The cogeneration of heat and electricity (Corera, J., 2006) does not mean a radical change compared to the heat and electricity production methods applied over the past decades, but it has high efficiency and a good rate of return (Plahn P., Keene, K., Pendray J., 2015). In addition to direct advantages, it has an indirect benefit, too: these units allow the DSO (distribution system operator) to establish a controllable and distributed energy production pool (Sioshansi, F., 2021), which nowadays means the technical basis of flexible service (Bozkaya, B., Zeiler, W., Boxem, G., 2014). Naturally, an application like that has to meet not only technical considerations, but requires the creation of a financially viable service package, either with participation in the regulatory reserve market or simply because of the basic functions: for the normal and emergency supply to the institution (European Council, 2022).

The application of gas engines for the improvement of the energy supply to hospitals has a decade-long history in Hungary, with both successful and less successful solutions. In the present market environment, and based on the significant (both electric and heat-side) energy demands of hospitals (Erdélyi, A., Pulay Gy., 2021), as well as the special distribution of this demand in time, a service package that offers a solution for the provision of essential, continuously available, reliable and quality energy supply (Elekes, A., 2018) may completely transform the present system of relations between hospitals and energy suppliers, creating an arrangement that is successful for both parties (Gurieff, N., Green, D., Koskinen, I., et al, 2020). Another reason why this research is particularly timely is the fact that the majority of the combined gas engine production units established for the KÁP/KÁT (mandatory takeover support, earlier KÁP) electricity sale, which was fairly widespread in the 2000s, have been technically fully amortised, moreover, the heat supply contracts of hospitals are close to expiry or already expired, and they are extended only temporarily with the present equipment and service provider. At the same time, as energy sites or locations, they are absolutely suitable for the maintenance, extension and modernisation of distributed and flexible, dispatchable capacities, and for realising the advantages of the cogeneration of energy and the saving of primary energy, which is an unavoidable task of the domestic energy sector in the tense natural gas market environment (Mihálovits, Zs., Tapaszti, A., 2018).

In our study, we worked out a possible concept for the direction of developing the service concept, whose main cornerstones are the following:

- With an attractive service offer, the DSO can be successful in supplying energy to hospitals and serving their individual requirements by establishing a new gas engine capacity.
- As a unique distinctive service, the provision of uninterrupted electricity supply makes the offer to the customer more valuable;
- In addition, the DSO supplies heat to hospitals free of charge or at a favourable price, by operating the gas engine and selling energy in the reserve market, and by selling electricity directly to the customer, which can greatly improve the available operation coverage;
- Together with the network-side synergy impacts (natural gas consumption, system utilisation fee), the combined production with

gas engines and offering heat supply for zero/low fees may be profitable.

As we mentioned before, the technical implementation proposals create the opportunity, while the direction will be determined by economic considerations.

In our article, following the definition of the subject, we summarise the possible technical and economic scenarios, and see what services could be offered with the optimisation thereof (Mancarella, P., 2014). In the next chapter, we present the technical simulation examination of the operation of the gas engine. In the fourth chapter, we discuss the operational issues and the cost structure. The mathematical model and the simulation analysis of operation monitoring are presented in the fifth chapter. The sixth chapter contains the evaluation of the tests, presents the optimisation of the operation, i.e. we describe the structure in which the gas engine could operate in a profitable way, in the case of an ESCO (Energy Service Company) investment project. Finally, we present the conclusion and the list of references.

UNINTERRUPTED POWER SUPPLY – OTHER CONCEPT

Gas oil-based engines, power generators

The traditional solutions for uninterrupted supply are power generators with combustion engines that can be operated from diesel energy sources, and often have container forms. With their classical design well known from traffic, they are reliable energy sources that start and reach the required performance quickly, but their use is significantly limited in practice by the supply of heating oil, their noise and the emission requirements, especially in urban environment. Their total nominal performance range is available, but the establishment of cogeneration is not typical in their case, i.e. the heat energy cannot be utilised.

Modern batteries (of Li-ion technology) are extremely flexible, they are characterised by high stored energy capacity and performance. However, due to their high investment costs, fire protection and security technology constraints, they are suitable for operation close to the user within a building to a limited extent only. For that reason, their advantages – low noise and no emission – are realised to a small extent; if they are located in a separate energy building, the traditional gas/diesel-based solutions can also be options. Because of the high investment cost and the net energy absorption, their operation costs return with continuous utilisation only. Profitable scenarios are presently known in the case of flexibility services of high added value. From the aspect of specific applications, another disadvantage is the lack of solutions for utilising the heat.

As gas engines can be regulated in a fairly flexible way, their technical characteristics may give them an advantage on the examined markets. Within their operation range, in the performance range of 40–100%, they can be regulated with a speed of 0.2–1.2 MW/minute, this way the conditions of the balancing regulation can be met, if it is possible to combine units of adequate capacities.

PROPOSED OPERATION MODEL

For the complex evaluation requiring technical and economic optimisation, we used several analysis layers that are built on one another.

The series of steps include the actual operation optimisation, too, which has a high rate of liberty in the case of flexible gas engines. (The ratio of possible and actual hours of utilisation is far from being 100%.) However, we carried out the calculations on the basis of a bottom-up time series technical operation simulation and operation cash flow calculation, and at the end, we evaluated the business model of the whole ESCO project.

The technical operation modelling of gas engines was divided into two parts: operation planning optimisation and operation monitoring simulation.

The result of the operation planning optimisation according to economic variables (prices, performance requirements) tells us how many gas engines should work in a given hour, with a given price and load, and sets their loads and the heat volume to be bypassed.

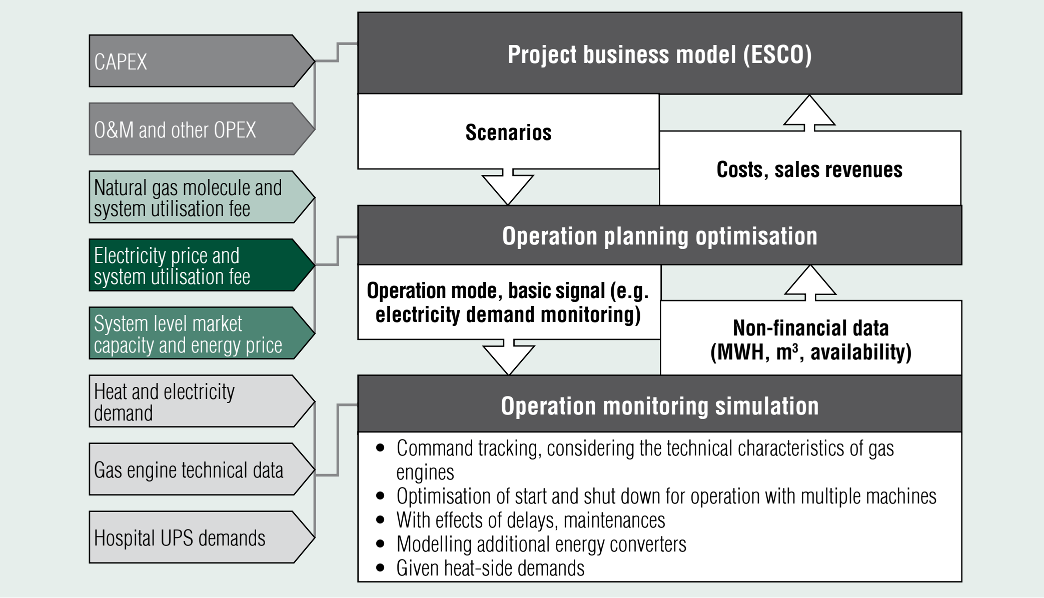
Because of the required results, the operation planning optimisation was carried out in every hour for the period from 2018 to 2040, so 200,000 times per scenario. For the sake of time efficiency, we defined the task in mixed integer linear programming (MILP) form. Some simplification has been made to it, because of the linear constraints, as we did not consider the load-proportional efficiency, which does not deal with the intertemporal constraints. However, the technical reality of the received basic signals was checked with simulations in the second phase of the modelling. The mathematical description of the optimisation is described in the Price and cost framework of gas engine operation chapter.

The operation monitoring simulation presents how the calculated gas engine electric base signal can be monitored according to the technical parameters of the available engines. This partial element of the simulation is of strong technical focus: it considers gradient limits, heat supply limits, coking in and out, availability and maintenance.

Figure 1 shows the relation between the calculation layers of the simulation framework and the data sources used.

Figure 1

RELATION BETWEEN THE CALCULATION LAYERS OF THE SIMULATION FRAMEWORK AND THE DATA SOURCES USED



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OPERATION MONITORING AND TECHNICAL SIMULATION OF THE GAS ENGINE

In the course of the operating time series simulation of the gas engine, a given technical optimisation and operation control takes place, corresponding to the operation requirement calculated by the operation planning optimisation and the basic signal, with multiple machines, considering the machine parameters, the heat and electricity constraints and possible downtimes, too.

Variables of the operation of the engine, based on the experiences of an earlier survey of small power plants:

- 98% availability (Samad, T., Koch, E., Stluka, P., 2016),
- 600 kW/minute regulation gradient per engine,
- Heat can be bypassed in the 0–80% range of the produced heat energy,
- Minimum 60% of the whole electricity capacity, up to 40% of the permanent minimum load (although limited in time) is allowed to reduce the performance (basically because of the mapping of the coking constraint).

The actual electric performance time series received as a result of the time series model implemented in MATLAB environment can be compared with the basic signal.

We applied a very detailed gas engine model for the operation monitoring simulation, which takes a number of technical constraints into consideration: heat demand monitoring, start and shut down times, coking, downtimes. The individual aspects are described in the following sub-chapters in detail.

A Modelling of heat system. The operation of the cogeneration of heat and electricity is significantly influenced by the heat-side requirements, so the heat system was mapped as a non-ideal storage. Supply over the current heat demand will charge this heat system, and the partial satisfaction of the heat demand will reduce the heat in the heat system (HIS). This modelled heat quantity might as well be negative (then the system is underheated compared to demands). Modelling the loss of the heat system and other heat sources feeding the system, the value of HIS continuously approaches zero, regardless of its sign, and in approx. one hour it goes down to a value of 88–90% *(Figure 2).*

B Following the heat demand. The gas engine follows the basic signal coming from the operation planning optimisation, but we calculate a heat basic signal, too, in each case. The latter considers the current heat demand and the volume of heat in the system (in the case of an earlier overheated system, it reduces supply, and in the case of an underheated system, it motivates supply). As the electric basic signal has priority, the gas engine attempts to follow the heat basic signal only as much as possible.

The operation state defined for the electric basic signal has a produced heat quantity belonging to it, too. If that is higher than the current heat basic signal, the gas engine releases the redundant quantity on the by-pass branches.

As the following of the heat basic signal may be overridden by the following of the electric basic signal, we managed the significant over- and underheating of the heat system with the implementation of two additional limits.

We parameterized the limit of the significant over- and underheating of the heat system with the heat system tolerance: applying the heat surplus or deficit actually present in the heat system to this allowed maximum value, we receive a relative value. In the case of high (over 50%) HIS values, the gas engine limits the heat that can be fed into the system (or, in

Figure 2

MODELLING OF THE HEAT SYSTEM (INDICATING THE QUANTITIES AS RELATIVE UNITS)

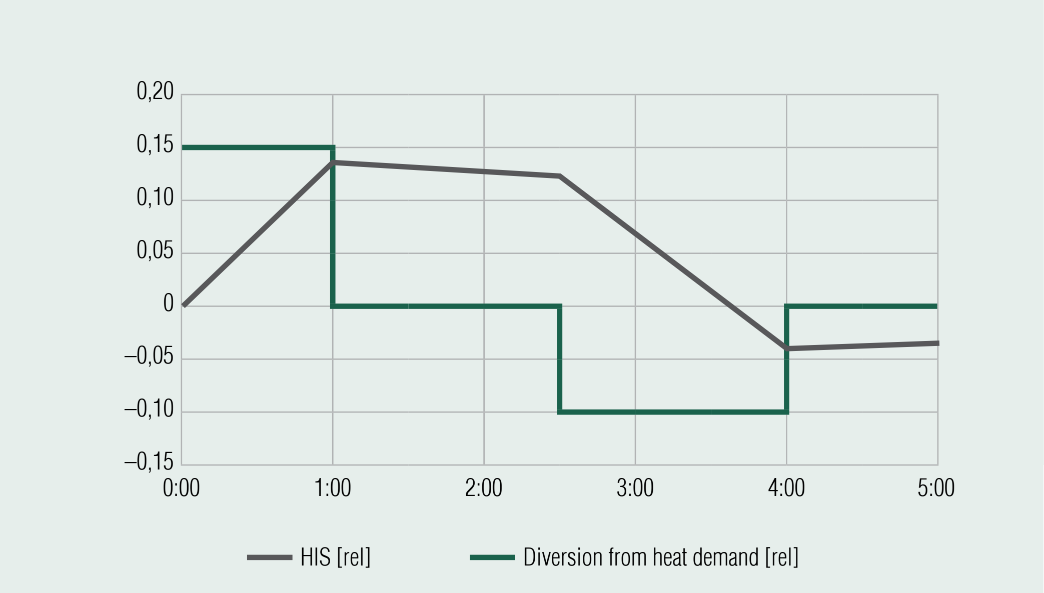

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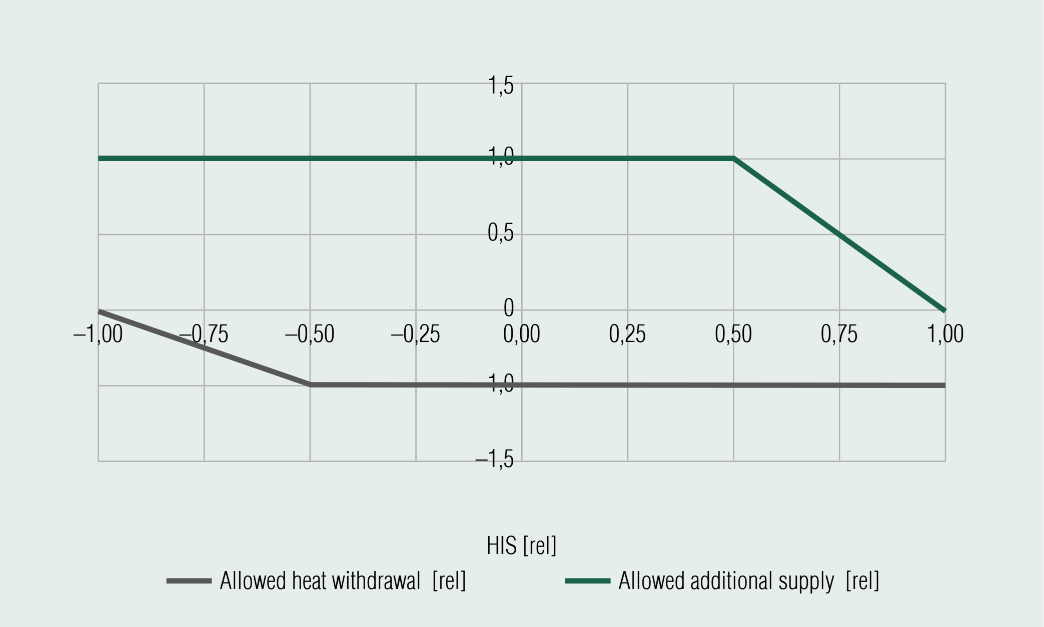
Figure 3

LIMITATION OF DIVERSION FROM THE HEAT DEMAND



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the case of a value below –50%, the heat that can be taken out) based on the characteristics in *Figure 3.* This limitation is able to override the electric basic signal of operation planning optimisation, too.

However, the first limit is still able to keep the system in over- or underheating for a longer period of time. Therefore, if the HIS>50% exists for a longer period (1 hour), the gas engine, as a second constraint, regardless of the operation planning optimisation basic signal, balances the HIS value with own control.

C Machine management (regulation, start, shut down, coking). The task of the operation monitoring simulation is to determine the optimal loads of individual gas engines for following the electric basic signal. The main steps of this algorithm are:

❶ Definition of the performance of the non-controllable gas engines

- Prohibiting the controlling of gas engines that are down/under maintenance.
- Increasing the load of machines that run with minimum load for too long (for coking out) – it is independent of the electric basic signal, and it is overridden by the technical expectations of the given gas engine.
- Continuation and completion of starts/shut downs started in previous period – it is independent of the electric basic signal, the start/shut down process of started/stopped machines has to be closed.

❷ Definition of the performance of controllable gas engines and the number of required gas engines.

❸ Commencing the necessary new engine start and shut down.

❹ Setting the basic signal of engines in operation.

Definition of the performance of the non-controllable gas engines

The non-controllable gas engines include the machines that cannot be operated because of maintenance/downtime. When the downtime occurs, the model immediately stops the given engine, without considering the gradient limit. Obviously, the output of non-operating machines is zero.

The technical requirements of gas engines allow a temporarily maintained minimum performance. However, this lower limit can be maintained only for 3 hours in the model, then the gas engine has to be 'coked out'. Coking out means that it has to be operated for at least 30 minutes, permanently, at least at the allowed minimum performance. The control model – if a gas engine runs in its temporary range for 3 hours – takes it out from the controllable machine group of operation monitoring, and runs it at the allowed minimum performance for 30 minutes. The load of this gas engine cannot be changed, but it is not zero, either, like that of the units down.

Finally, engines under start/shut down also belong to the non-controllable units. Their performance is between zero and the temporarily allowed minimum performance, and depending on the command, their performance continuously rises (increase) or goes down (stop) with the allowed gradient.

Definition of the number of machines in operation

The performance of non-controllable machines is fixed, and it is deducted from the electric basic signal. The remaining performance has to be achieved by specifying the basic signals of controllable machines. As the machines can be operated with partial load, too, it happens that a given load does not determine clearly the number of engines to be kept in operation. For example, in the case of 2 pieces of 800 kW gas engines, 720 kW performance can be achieved with two engines (360 kW+360 kW, 45% load), and with one machine, too (720 kW, 90% load).

The necessary new engine start and shut down

The number of machines to be actually kept in operation is defined by the model with the following simple rules. It stops only as many engines as absolutely necessary. If a machine has to be started, it is always done. It may happen that the algorithm says that a machine should be started, but there is no machine that could be started (e.g. it is down). In this case, of course, the controllable machines will work more intensively to reduce the error.

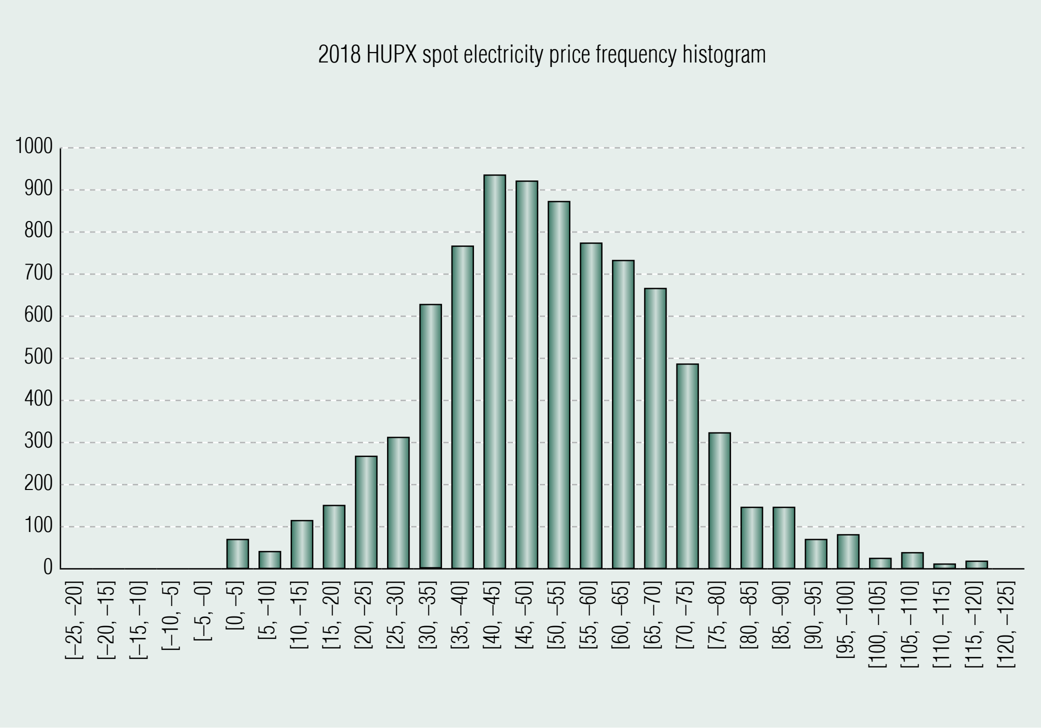
Setting the basic signals of engines in operation

The available and operating machines that are not down have no maintenance or coking out phases, thus have to meet the remaining basic signal during start or shut down. This logic is very similar to the start:

- if the performances have to be increased, first the load of engines under bigger load is increased (maximum to nominal);
- if their total performance has to be reduced, the load of the engines under smaller load will be reduced.

Figure 4

DEVELOPMENT OF ELECTRICITY PRICES ON THE DAY-AHEAD EXCHANGE



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PRICE AND COST FRAMEWORK OF GAS ENGINE OPERATION

Price components of energy sources

Wholesale price of electricity

Regarding the power plant sales, we calculate with hourly energy price changes, which are based on the day-ahead spot settlement price time series of the HUPX (Hungarian Power Exchange) in 2018 *(Figure 4)*.

For the rest of the years, we calculate with the same within-the-year price profile, which will be indexed with the changes in the future average continuous supply price (base product). Regarding these, as long as there is a listed settlement price on the domestic futures electricity market, i.e. for four years ahead, we take the power exchange prices into consideration. For the forthcoming years, we assumed a conservative annual growth of 3%.

Wholesale prices of natural gas

In the case of natural gas, regarding future wholesale pricing, we followed the same methodology as for electricity. It is a minor difference compared to electricity that because of the strong liquidity of the TTF, market listing is for 5 years ahead, so it is available for 2019–2023, too, therefore we considered the increasing indexing of 3% per year from 2024 only.

Heat supply sales prices

As a starting point for sales prices regarding heat supply, we used the relevant earlier data of the examined hospital as follows: heat fee, gas fee, steam fee.

The heat fee is a fee to be paid for the quantity of heat metered by the heat quantity meters and supplied through the hospitals' heat centres. In the case of a hospital, this item refers to heat quantities delivered in the forms of hot water, heating and steam.

We calculated the heat fees on the basis of the changes in gas fees, based on the efficiency of the gas-heat conversion.

The gas fee is the cost of natural gas fixed in the contract and charged to the heat customer, this is actually a transit item in most contracts. In the majority of the examined contracts, the heat fee to be paid is indexed on that basis.

The steam fee is the amount to be paid for steam received. Certain contracts do not define separate steam fees, but specify them on the basis of the heat fee, taking the enthalpy of the steam into consideration. The usual conversion rate is approx. 2.5 GJ/ton.

System-level service market revenues and the balancing cost

For gas engines aggregated as virtual power plants, the regulatory reserve market may provide a very attractive business model, owing to their ability to change performance quickly. In the case of the engines, the capacity market of the faster and so more valuable aFRR (secondary) product is relevant, for both upward and downward regulation.

The sales prices of system-level services were defined on the basis of the latest quarterly reserve contracting tenders, as the average of the results in the period of 2018 Q3 – 2019 Q2. As gas engines are of high utilisation in the scenarios (this is how they support the UPS service, too), the sales price to be realised can be approximated with good precision with the annual average market price.

Data of operation and investment costs

We carried out a detailed analysis of the literature regarding the investment and operation costs of gas engines. Maintenance tasks and overhauls are particularly significant items among expenses. Apart from the typical minor repairs and inspections after 1,000 and 2,000 hours of operation, it is necessary to have an overhaul after 8,000–16,000 hours, and a complete overhaul (turbo replacement, new sleeves etc.) after 45,000–80,000 hours. In practice, this means that before the complete overhaul due after 10 years, it is necessary to define the maintenance costs and the business value of the gas engine again, and decide whether the machine unit would produce the price of the overhaul in its remaining life-cycle of typically 30,000–50,000 operation hours. Different sources present the operation costs of gas engines in different ways. Certain costs are scaled with the built-in performance of the machine, so they mean fixed type of O&M costs. However, several analyses determine all operation and maintenance costs specifically for the electricity produced, so they calculate with variable O&M only. Nevertheless, all of the variable service cost calculations include the various overhauls, too. The data mentioned in individual references are included in *Table 1* in detail.

Based on all that, calculating with a conservative estimation approach in the model calculation, the CAPEX specific unit price, which contains the whole investment cost, is EUR 2000/kW, the fixed O&M is EUR 30/kW, while the variable O&M is EUR 5/MWh. Operation costs increase by 3% per year, following the growth of the service that is expected to be in line with long-term inflation rate.

MATHEMATICAL MODEL OF THE OPERATION MONITORING SIMULATION

The mathematical formalisation of the operation planning optimisation is shown with the joint controlling of two gas engine units. The decision variables related to the machines are shown in *Table 2*.

Table 1

COMPARISON OF PRICES ON THE BASIS OF AVAILABLE LITERATURE AND BUSINESS SOURCES

Source	CAPEX machine unit [€/kW]	CAPEX other [€/kW]	Fix O&M [€/kW]	Variable O&M [€/MWh]	Total O&M [€/MWh]
Energinet, 2018	1,000	–	10	5.4	6.7
IEA-ETSAP, 2010	870	–	35	0.0	4.7
EPRI, 2017	900	–	30	4.9	8.9
EIA, 2016	1,170	–	6	5.1	5.9
MIT, 2016	1,500–3,000	–	0	8.0–10.5	8.0–10.5
Wartsila, 2018	?	–	?	5.0	5.0<
EPA, 2015	1,325	675	0	20.0	20.0
Energy.gov, 2016	950–1,150	–	0	14.0–16.5	14.0–16.5
MDPI, 2017	?	–	?	6.5	6.5<

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Table 2

DECISION VARIABLES OF MACHINES

Name of variable	Range of interpretation	Description
op_1, op_2	{0;1}	the gas engine operates
LD_1, LD_2	[0;1]	relative load on gas engine
$bypassed_1$, $bypassed_2$	[0;maxbypassableheat]	bypassed heat of gas engine [kW]

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The maximum value of the bypassable heat is a technical parameter (maxbypassableheat), it is given as the input of optimisation. The relation between the operation's binary variables (*op*) and the continuous variables describing the load (LD_1, LD_2) is ensured by the following forces, which prescribe the minimum allowed load, too, as follows:

$$minLD-(1-op_1)\,minLD \leq LD_1 \quad (1)$$

$$LD_1 \leq op_1 \quad (2)$$

If the gas engine is out of operation ($op=0$), then, based on the above limits, the load is 0. Otherwise ($op=1$) the load is limited from below by *minLD* given as a parameter, and from above by the binary variable itself – the value of which is then 1, i.e. 100%.

Apart from the above simple logic, we established the following limits on the basis of the market logic. Optimisation runs for one hour ($\Delta t=1h$), so we can derive the necessary gas energy from the performance, using the gray auxiliary variable.

$$E_{gas}=P_{gas}(LD_1+LD_2)\Delta t \quad (3)$$

Electricity production is calculated with the electric efficiency (μ_{el}):

$$E_{el}=E_{gas}\,\mu_{el} \quad (4)$$

The generated electricity can be used for two purposes: it is either sold on the organised electricity market (*EM*) ($E_{el,EMsold}$), or it satisfies the electricity demand of the hospital ($E_{el,LDsold}$), but in the equation, each member can only be positive:

$$E_{el}=E_{el,LDsold}+E_{el,EMsold} \quad (5)$$

However, the electricity demand of the hospital can be satisfied not only from the electricity generated by the engine ($E_{el,LOADsold}$), but by purchasing from the HUPX ($E_{el,HUPXbought}$), too:

$$E_{el,demand}=E_{el,LDsold}+E_{el,EMbought} \quad (6)$$

In addition to the electricity and heat energy supply, in the regulatory reserve (*afrr*) it is possible to offer the remaining capacity of the whole site both upwards (E_{afrrp}), and downwards (E_{afrrn}) in the case of integration into a regulation centre. We would like to note here that in the case of downward reserves, the regulation centres usually do not consider the minimum load of individual gas engines, as in the case of a large number of engines, the required downward capacity can always be ensured for a short period of time, and owing to the high gradient ability, the stopping of one gas engine now and then presents no technical limitation.

$$E_{afrrp} = 2E_n - E_{el} \tag{7}$$
$$E_{afrrn} = E_{el} \tag{8}$$

Apart from electric and technical limitations, the heat produced by a unit ($E_{heatprod}$) is a boundary condition regarding heat production. The heat produced by individual units is determined by the heat efficiency ($\mu heat$) :

$$E_{heat\_prod1} = P_{gas}\, \mu heat\, LD_1 \tag{9}$$
$$E_{heat\_prod2} = P_{gas}\, \mu_{heat} LD_2 \tag{10}$$

The heat fed into the heat system ($E_{heatsupply}$) can be regulated with bypassing:

$$0 \leq E_{heat\_supply1} = E_{heat\_prod1} - bypassed_1 \tag{11}$$
$$0 \leq E_{heat\_supply2} = E_{heat\_prod2} - bypassed_2 \tag{12}$$

Finally, the relation of the demand of the heat system ($E_{heatdemand}$) and the supplied heat contains the heat quantity not served ($E_{el,notserved}$).

$$E_{heatdemand} = E_{heat\_supply1} + E_{heat\_supply2} + E_{el,notserved} \tag{13}$$

After the limitations, we give the definition of the objective function, which contains the following cost elements:

- EM transaction costs ($E_{el,EMsold} – E_{el,EM,bought}$) at the organised electricity market price (p_{EM});
- the revenue from the electricity sold to the hospital ($E_{el,demand}$) at fixed trading price (p_{el});
- the revenue from the upward and downward reserves' availability fees (p_{afrrp}, p_{afrrn}) ;
- the heat revenue, which is only paid on the heat demand, if that is served by the gas engine, pheat being the price of one unit of heat;
- finally the cost of the primary energy (natural gas) (p_{gas}).

$$\begin{aligned}(E_{el,EMsold} - E_{el,EMbought})p_{EM} \\ +(E_{el,demand})p_{el} \\ +E_{afrrp}p_{afrrp} \\ +E_{affrn}p_{afrrn} \\ +(E_{heatdemand} \\ -E_{elnotserved})p_{heat} \\ -E_{gas}p_{gas}\end{aligned} \tag{14}$$

DESCRIPTION OF OPERATION OPTIMISATION SCENARIOS

For the schedules defined for 2020 in the course of operation optimisation, the operation monitoring simulation was carried out for each examined scenario. We checked the precision of operation, the keeping of the schedule, and the meeting of technical limits (start numbers, partial load). We calculated the run times of machines in categories according to load states (in % for the times with full load and partial load). In the latter, the <1% value that can be seen in several scenarios is negligible, as that is practically related to the increases after start. The difference between the required basic signal and the actually generated electricity causes a balancing energy cost, which was also calculated with time series.

The examined gas engine versions were selected from Jenbacher's machine families 3, 4 and 6 (Chengyang, L., Jing Yang, R., Yu, X., et al, 2021). In the product range of other manufacturers, in the examined range of 1–2 MW, there are products very similar in key parameters, so the selection of this manufacturer may also provide results to the general statement.

The heat performance, electric efficiency and performance data of gas engine types suitable for the site are included in *Table 3*. *Table 4* compares the various configurations.

Based on the performance requirements and conditions of the site, as well as the size categories of the gas engine product series, we calculated as follows:

Table 3

COMPARISON OF GAS ENGINES SUITABLE FOR THE SITE

Type	El. perf. [kW]	Heat performance [kW]	Electric efficiency [%]	Number of gas engines
Jenbacher 3				
J312	635	739	40.8	3
J316	851	991	40.7	2
J320	1,067	1,241	40.9	2
Jenbacher 4				
J420	1,497	1,563	42.9	1
Jenbacher 6				
J612	2,017	1,930	45.2	1

Source: own editing

Table 4

COMPARISON OF VARIOUS CONFIGURATIONS

	aFRR+ [MWh/ year]	aFRR– [MWh/ year]	Heat sale [MWh/ year]	El. production [MWh/ year]	Gas consumption [MWh/ year]	δ	Primary efficiency (%)	Electric efficiency (%)
3x635kW	2,799	13,843	16,110	13,843	33,928	0.86	88.3	40.8
2x1067kW	3,108	15,535	18,068	13,772	37,982	0.76	83.8	36.3
1x2017kW	2,659	14,962	14,316	13,193	33,101	0.92	83.1	39.9

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Table 5

COMPARISON OF OPERATION STATES

Engine configuration	Load (idle-partial load-full load) [%]	Specific balancing costs [€/kW]
3xJ312	21-0-79	17.6
2xJ316	16-6-79	17.3
2xJ320	22-0-78	16.1
1xJ420	21-0-79	22.1
1xJ612	20-0-78	22.3

Source: own editing

- in one-machine configuration with types J612 and J420,
- in two-machine configuration with units J316 and J320,
- in three-machine configuration with machine J312.

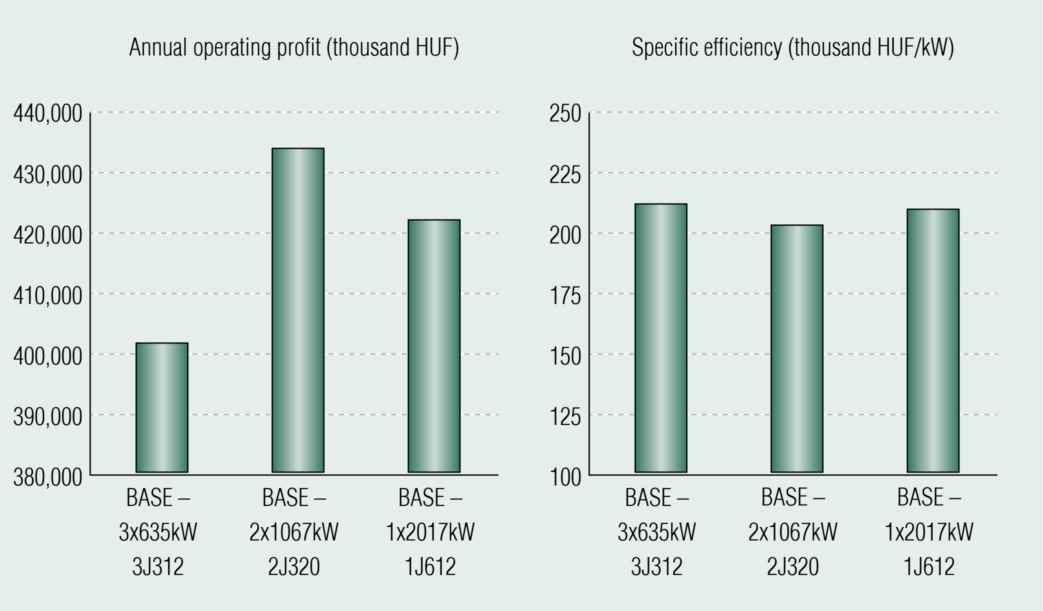
During the run, the pure objective is to maximise operational effectiveness with the given energy demands and prices. Therefore, in this case, it is possible to satisfy the energy demands of the hospital from the market or the power exchange, too, if that is more favourable than own production. The heat demand of the hospital is close to the nominal performance of the examined gas engines, and heat sale is possible almost continuously.

In order to reduce the diversity of possible alternative scenarios and the technical and operational combinations, first we selected configurations – with one, two or three gas engines – that would be suitable from the aspect of operation (number of starts, nature of partial loads), from the 5 cases presented in *Table 5*. The operation monitoring analysis gives an exact time series result for the volume of the balancing energy and its costs, too, in addition to the actually realised gas engine operation states. For the period of running, the distribution of the operation states of gas engines and the development of balancing costs are included in Table 5.

As to the examined engine combinations, one of the key issues is optimal sizing, as the large number of hours of utilisation basically determine the return. In the case of the configuration modelling 2 pieces of J316 engines, the optimal operation adjusted to the examined energy demand curves leads to operation with partial load in a lot of cases, while the scenario of 1 piece of J420 was rejected because of its worse return and higher specific investment costs.

Figure 5

COMPARISON OF RESULTS FOR THE 1-2-3-MACHINE SYSTEM



Source: own editing

The balancing costs amount to approx. EUR 20–25 thousand/year, i.e. make up 1–2% of the whole revenue and 3–5% of operation costs. This way balancing costs in themselves do not cause a significant deterioration of the return prospects, but, as it was expected, one-machine set-ups offer somewhat poorer results.

Comparing the annual operation of the selected one- and three-machine set-ups (*Figure 5*), although the general utilisation is not higher in the case of several machines, we can still define several periods when individual engines should join the system even with lower performance.

We examined the results of schedule optimisation for the next 10 years for the three priority technical scenarios. The sold flexibility and reserve capacity change proportionally with engine utilisation and the built-in capacity in the case of the aFRR product. In the case of the aFRR+, i.e. power in-feed, the relative disadvantage of the three-machine system is reduced compared to the two-machine arrangement.

It is also worth pointing out that the nominal gas engine efficiencies (belonging to the full load) can only be realised to a limited extent in reality, and the more flexible three-engine set-up – owing to less partial load – has a better efficiency, than the machines of series 6 that are more efficient in the base load production.

When calculating the annual average operational spread calculated with the simplified method, we took the revenues from heat and electricity sales, the natural gas costs and the balancing energy costs into consideration, too. As presented in *Figure 5*, the absolute efficiency differs by about 7–8 per cent between the two extreme values, but the specific – i.e. proportionate to the investment cost – indicator projected on the total capacity shows only 3.5% as the biggest difference, and the sequence of the engines has changed, too.

Based on the above points, we can say that in the course of profit-optimised operation, the three types of set-ups work in similar ways, but according to several other considerations, the three-machine set-up is the most favourable version.

We can look for other differences between the cases by considering the CAPEX and other OPEX items, and in the case of the modified basic signal optimisation. The calculation of returns for the whole project and the analysis of the operation with the modified basic signal will help the selection of a robust solution from the options, even in the case of a wider range of future uncertainties.

SUMMARY

The utilisation of UPS devices in the uninterrupted power supply of hospitals had varying degrees of success in the past. However, the present technical and economic environment and the typical temporality of hospitals' need for electricity and heat energy may completely change this picture. In the article, the authors presented a study, which was aimed at assessing the dependence of the UPS business models on several factors, including margins, heat energy revenues and annual consumption factors. Case studies were presented for the one-, two- and three-machine configurations. The comparison of these cases showed that while in the case of using multiple machines, the average utilisation factor is not higher, and the temporality of electricity and heat energy demands offer better opportunities for starting smaller units. In the case of the aFRR service, the sold flexibility (reserve capacity) is proportionate to the utilisation and the nominal capacities of the operating UPS devices. The case of aFRR+ services (upward regulation) indicates the relative reduction of the disadvantages of the three-machine system, too, compared to the two-machine configuration.

With the assumption of the basic case, favourable returns can be expected. The positive cash flow of the project is steady during operation, the expected life-cycle is until 2033–36, depending on the hours of operation. The results of scenarios are favourable in the case of market price level: with a base fee, IRR is 11.0–11.5%, and it is favourable without base fee, too, 8.3% (in 2019, not with premises of 2022).

Several sensitivity tests were conducted with the scenarios containing the basic signal optimisation. The CAPEX/OPEX increment, the delay in investments have negative impacts, a delay of 1 year and/or a 10% increase in investment costs means a 1.5% drop in IRR. The tax was defined with approximation calculation, not only the impacts of the corporate tax (9%) and the income tax impact of energy suppliers (31%) can be calculated, but possible profit-sharing schemes, too. The one-third share allows the project to almost break even.

The final conclusion of the authors is that if the operation of the UPS units relies exclusively on profit optimisation, the three-machine configuration shows a steady performance in each respect, and other major benefits can also be seen if we consider other aspects, too, especially with business objectives. ■

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