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Small Cogeneration Unit with Heat and Electricity Storage

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Abstract: A micro cogeneration unit based on a three-cylinder internal combustion engine, Skoda MPI 1.0 L compressed natural gas (CNG), with an output of 25 kW at 3000 RPM is proposed in this paper. It is a relatively simple engine, which is already adopted by the manufacturer to operate on CNG. The engine life and design correspond to the original purpose of use in the vehicle. A detailed dynamic model was created in the GT-SUITE environment and implemented into an energy balance model that includes its internal combustion engine, heat exchangers, generator, battery storage, and water storage tank. The 1D internal combustion engine model provides us with information on engine start-up time, actual effective power, friction power, and the amount of heat going to the cooling system and exhaust pipe. The catalytic converter was removed from the exhaust pipe, and the engine was always operating at full load; thus, engine power control is not considered. An energy storage system for an island operation of the entire power unit for a large, detached house was designed to withstand accumulated energy for a few days in the case of a breakout. To reach a low initial system cost, the possible implementation of worn-out battery packs toward emission reduction in terms of the second life of the battery is proposed. The energy and emission balance are carried out, and the service life of the engine is also discussed.

Keywords: energy transition; cogeneration unit; CNG engine

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1. Introduction

With increasing demands toward cleaner environmental conditions, a combination of a unit generating electric and heat energy is an excellent step to fulfill the requirements toward decreasing carbon dioxide (CO_2) emissions and the overall healthy living of human beings that will habit our planet in future decades and centuries. The is talk about cogeneration units, also called combined heat and power (CHP) units, which can generate power at a large scale to supply energy for defined places such as houses, offices, shops, etc., in short distances. Instead of dissipating the heat generated from engines into the atmosphere, the waste heat produced can be recycled by heat exchangers (HXs) to heat the water in reservoirs and save a significant amount of heat energy that would otherwise be unused in conventional sources of power. With the possibility to operate as a standalone unit independent of a national grid, it can be used as an island operation unit in remote locations, where no connection to the electric grid is available. However, this is not the only purpose for such a unit. Whereas the CHP unit is connected to the grid, and the energy system consists of other integral parts such as HXs and storage units, a control system can reasonably manage energy demands. Thus, in daily energy demand peaks, energy can be supplied into the electric grid, saving the owner's money. Many papers have concentrated on the proper setups for energy storage in order to react to the varying prices of electricity throughout the day and sell the excess energy or buy some if needed [1]. The absence of crude oil is expected in the following decades due to an alarming rate of the diminishment of fossil-fuel reserves in the world [2]. Sources of alternative fuel for internal combustion engines are currently becoming more popular and replacing conventional fuel systems. When choosing a proper micro-CHP unit, several properties should be considered. One of them is the choice between a turbine or reciprocating engine or the type of fuel used in the CHP unit. In this paper, the main issues that can influence the practical implementation of a three-cylinder internal combustion (IC) engine, Skoda MPI 1.0 L compressed natural gas (CNG), used as the CHP unit for a large, detached house, are investigated. CNG is composed primarily of methane, but it may also contain ethane, propane, and heavier hydrocarbons, as well as small quantities of nitrogen, oxygen, carbon dioxide, and water. The main benefits of CNG against conventional fuels are that it does not contain sulfur, particulate matter, traces of heavy metals, or toxic additives [3]. CNG is a clean-burning fuel and is considered to be the cleanest of all fossil fuels. It has been recognized as one of the promising alternative fuels due to its significant benefits compared to gasoline fuel and diesel fuel [4]. The current generation of natural gas engines offers a low initial cost, fast start-up, proven reliability when properly maintained, excellent performance characteristics, and significant heat recovery potential. Gaseous fuel distribution is well developed in many countries, and these fuels are less expensive than petrol due to tax differences and subsidies in some countries. Among the other benefits of using CNG is that in the case of a leak, CNG does not pose any danger of the contamination of groundwater because the fuel is nontoxic [5]. The average price in Europe for 1 kWh energy from natural gas is 0.0656 EUR/kWh, whereas for 1 kWh of electric power from a grid, it is 0.2126 EUR/kWh, according to Eurostat [6]. In this article, we discuss the problem of the implementation of a standalone energy supply system for residential purposes with the possibility of a small initial investment into the components. This study also offers an insight into the utilization of aged electric vehicles (EVs) as stationary energy storage because firstly developed EV batteries are currently reaching the end of their life cycle. For residential purposes, such energy storage, even with decreased capacity, offers huge potential in the reduction of emission because recycling technology of used batteries is still not well developed.

2. Energy Supply System

The main part of the CHP system discussed in this paper is the IC engine mentioned above. Micro-CHP units of 5–50 kW_{el} are commercially available on the market. Most of these are based on reciprocating engine technology, but a few small appliances based on gas turbines can also be found. These units have a heat-to-power ratio of about 2:1, and the heat output is generally within 15–120 kW. The utilization of CHP-based reciprocating engines has higher electrical efficiencies than gas turbines of comparable size, with lower fuel-related operating costs (decreased gas emissions) but with generally higher maintenance costs [7]. The long history of technical development and high production levels have contributed to making reciprocating engines a rugged, reliable, and economical choice as a prime mover for CHP applications. In on-site power generation applications, the economics of engines often depend on the effective use of the thermal energy contained in the exhaust gas and cooling systems, which, in general, represents 60 to 70% of the inlet fuel energy [8]. The idea of waste heat treatment and power generation in reciprocating engines is depicted in Figure 1. Most of the waste heat is available in the engine exhaust and the jacket coolant, and smaller amounts can be recovered from the lube oil cooler. To utilize all the advantages that the CHP system offers, it is desired to add a heat storage tank and battery accumulator into the system to increase the efficiency of the system together with the optimization energy controller, which operates with the heat and electric demands (see Figure 2). CHP is usually designed for defined applications with its energy demands and most of the time operates continuously as frequent starts are not desired and negatively contribute to the faster wear-out of the engine [9]. While connected to the grid, the energy controller then determines if the energy will be used immediately, stored, or sold/purchased into/from the grid. In this article, an island operation is proposed. This means that no further power is added from a national grid, and the whole sector uses energy produced only by the CHP unit; in this case, by the IC engine without the opportunity of selling the energy to the grid. Unlike the majority of industrial projects that can absorb the entire thermal output of a

CHP system on-site, many residential houses have either a small thermal load or a highly seasonal load such as space heating.

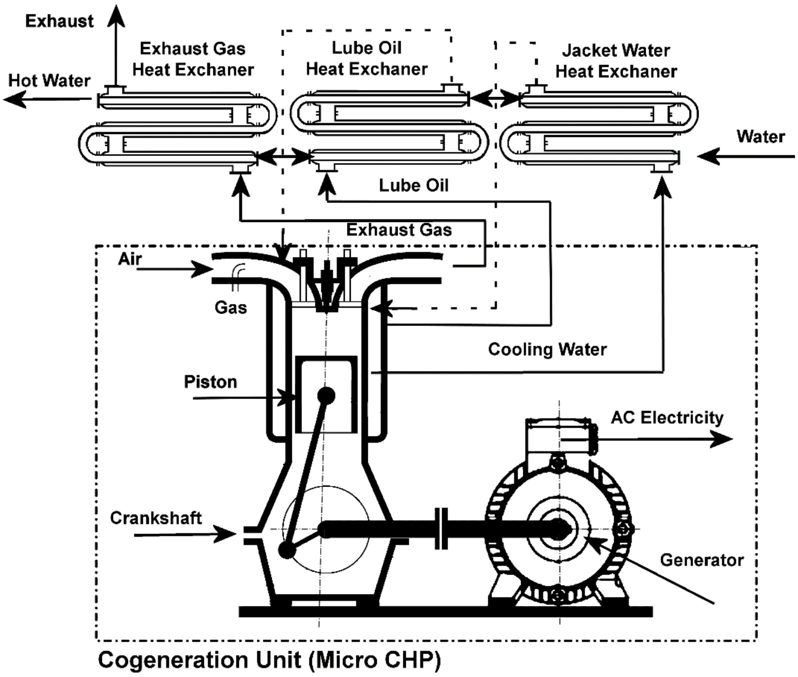

Figure 1. Waste heat treatment in micro combined heat and power (CHP) units.

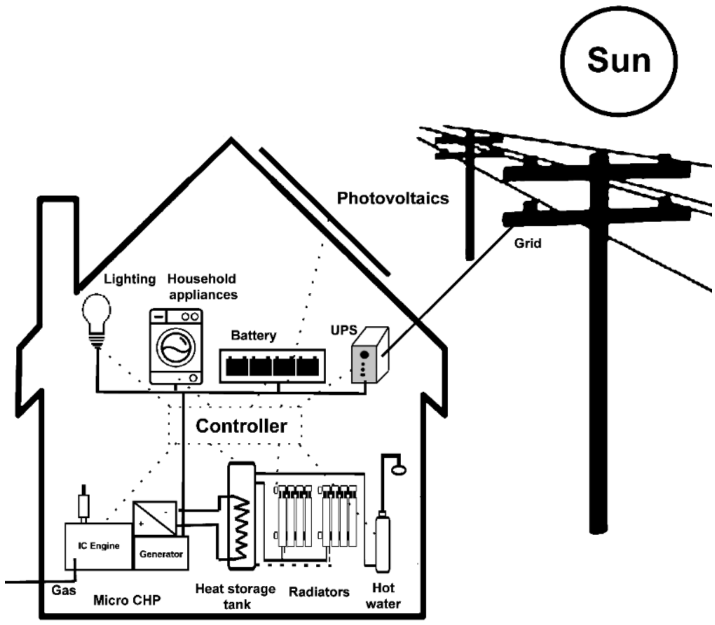

Figure 2. Residential micro-CHP distribution system.

The best overall efficiency and economics of CHP systems come from a steady thermal load. However, the fundamental problem is that the annual production of electricity is determined by the amount of usable heat that is generated throughout the year [10]. If no hot water is needed, the amount of heat recovered from the engine is reduced, and the total CHP system efficiency drops accordingly. In this work, the focus is concentrated on a large, detached house, where the energy consumption is assumed to be high. Due to the availability of the engine on the market, which satisfies low initial costs for the CHP but offers a great amount of energy that should be used in order to fulfill the efficiency potential of the CHP system, it is assumed that the house can consume up to 15 kWh of electricity intake for all the appliances and 30 kWh of heat energy in winter during the coolest days. With such a strong engine used in this case, it is desired to operate only for 1–2 h a day to fulfill the overall daily energy consumption and prolong the time until the engine overhaul. While choosing the proper heat energy storage, sensible (water) or latent heat storage (filled with phase change material) can be used. In the case of latent heat storage, the space for such a tank is significantly smaller, but the storage price is marginally higher [11]. Due to the low initial costs of the system components, only sensible heat storage is considered in this work. The quantity of energy stored by a sensible heat storage device depends on the mass and specific heat of the storage medium, as well as the temperature difference between the initial and final temperatures. Water is the most widely used material for sensible heat storage because it is relatively easy and inexpensive to store at temperatures usually up to 80–90 °C in atmospheric pressure systems. To reach a low initial cost and reduce greenhouse gas emissions, a battery accumulator was selected from the car industry. The volume of produced new batteries that will not reach an end-of-life status is significant and still increasing. Circular energy storage Creation Inn estimated 5800 to 30,000 tons of lithium carbonate equivalent, and 22,500 tons of cobalt is expected to be recycled by 2025 [12]. Despite these, there is a limitation when it comes to the availability of the recyclable volume of material because of poor collection systems for portable batteries. This aims to provide a second life for vehicle batteries such as that in the Tesla Model S (lithium-ion battery pack of an 18,650-battery cell) with its initial battery size in the most current design versions of 85 kWh. Such a battery accumulator offers a huge opportunity in the case of CHP breakdown problems that can withstand without energy generation for several days. In the case of worn-out batteries, the capacity is lowered due to the aging battery process and assumed to be of about 80% of its initial capacity after 225,000 km of driving [13]. Nevertheless, for residential electric accumulating purposes, it is still a very large battery, and from an emission point of view, it accounts for better environmental potentials because the battery does not need to be immediately recycled and can serve other purposes than for which it was initially designed.

3. Model Configuration

In this work, a reciprocating engine from a small vehicle used, mainly the Skoda CITIGO, is described. It is the 1.0 L three-cylinder MPI engine. These units are manufactured in two variants: a classic petrol unit and a CNG unit. It was decided to choose a variant with CNG fuel because it exhibits better environmental impacts. The motor reaches compact dimensions, and due to the optimization, friction losses and the weight of the entire unit are also reduced. The performance of the engine is depicted in Figure 3, and other important parameters of the engine, such as the compression ratio, air/fuel ratio, etc., are provided in Table 1.

Table 1. Description of the engine, Skoda MPI 1.0 L CNG.

Engine Displacement (cm^3)	**Bore (mm)**	**Stroke (mm)**	**Compression Ratio (–)**
999	74.5	76.4	11.5
Maximum Power (kW)	**Maximum Torque (Nm)**	**Fuel (–)**	**Air/Fuel Ratio (–)**
38 at 5000 rpm	83 at 3000 rpm	CNG	1.1

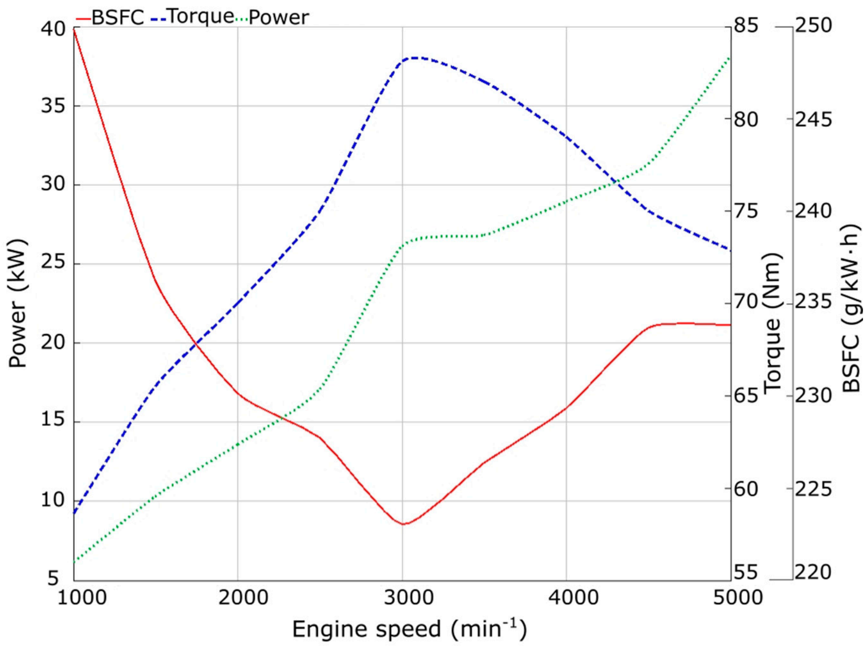

Figure 3. Engine performance of Skoda MPI 1.0 L compressed natural gas (CNG).

The maximum engine power output of 38 kW was measured at 5000 RPM, but in terms of the economy and long life of the CHP system, it is not a practical stationary regime. At 3000 RPM, brake-specific fuel consumption is at its minimum of 223.7 g/kWh and thus offers economic engine operation, while engine torque is at its maximum of 83 Nm. The basic energy balance (see Figure 4) for the description of the engine was used and can be calculated as follows [14]:

$$A_e = \dot{m}_p H_U \eta_c \eta_t \eta_v \eta_m, \tag{1}$$

where A_e is the generated electric energy (kW), $\dot{m}_p$ is the mass flow of the fuel into the combustion chamber (kg/s), H_U is the heating value of the fuel (kJ/kg), η_c is the efficiency of the combustion/chemical efficiency (–), η_t is the thermal efficiency (–), η_v is the volumetric efficiency (–), and η_m is the mechanical efficiency (–), which is described as friction losses in the mechanism.

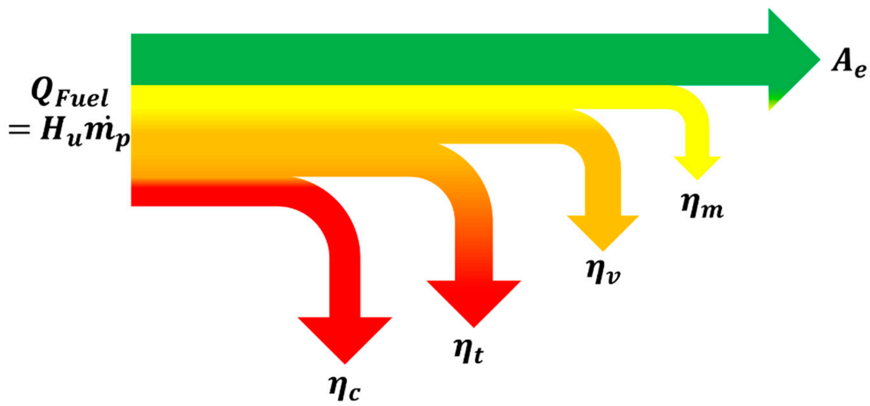

Figure 4. Energy balance of the engine.

The results of the energy balance of the engine at the engine speed of 3000 RPM are listed in Table 2 with the values of energy dissipation of usable electric energy, losses due to friction forces and waste heat energy, which can be recovered in the exhaust pipe system and heat transfer into the engine jacket.

Table 2. Energy balance of the internal combustion (IC) engine, Skoda MPI 1.0 L CNG, at 3000 RPM.

	Energy in Fuel	Usable Energy	Electric Energy	Friction Losses	Exhaust Energy	Heat Transfer
Energy (kW)	80.9	73.8	26.1	3.5	30.8	13.4
Fuel Energy (%)	109.6	100	35.4	4.7	41.7	18.2

A dynamic model of the IC engine and the whole CHP system is shown in Figure 5. This model was developed in GT-SUITE software. The model includes an engine-cooling circuit, an exhaust pipe system with HX and a hot water tank, as well as the synchronous generator and battery accumulator. GT-SUITE software, which includes the GT-POWER engine library, is the leading engine and vehicle simulation tool used by engine manufacturers and suppliers. It is suitable for the analysis of a wide range of issues related to a vehicle, engine performance, and other applications, such as cooling, lubrication, waste heat recovery, etc. Engine performance is designed for steady-state and transient simulations and can be used for the analysis of engine and powertrain control. It is applicable to all types of internal combustion engines and provides users with many components to model almost any advanced concept. The solution is based on one-dimensional fluid dynamics, representing the flow and heat transfer in the piping and other flow components of an engine system. In addition to the fluid flow and heat transfer capabilities, the code contains many other specialized models required for the system analysis.

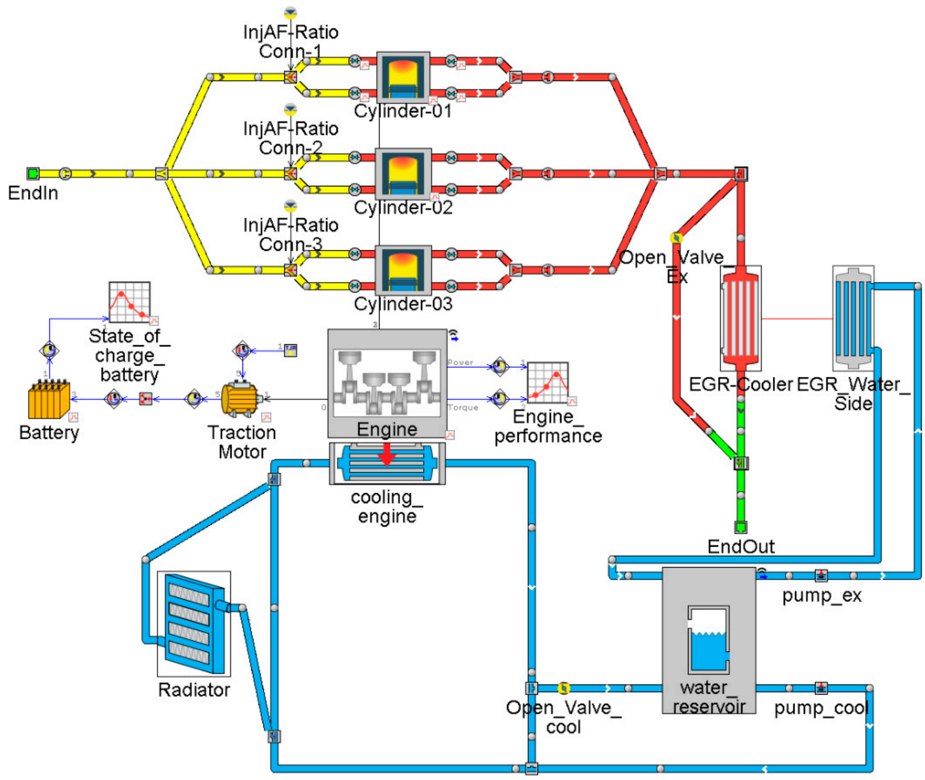

Figure 5. Dynamic model of the CHP unit in GT-SUITE.

These simulations are used only to determine the basic energy balance of the system, and the simplest models are used to describe the individual components. The electrically equivalent battery model is used, in which the input parameters are the number of cells in series and in parallel, as well as their capacities and the properties of the electrical circuit. These values match a real Tesla battery pack. The battery model is also called a resistive or Thevenin electrical-equivalent battery model [15].

The usable electric energy 26.1 kW is set for the engine speed of 3000 RPM and is further reduced due to the transfer efficiency using the direct shaft connection, which is 98%. Synchronous generator efficiency reaches 92% after 23 s from start-up, and the stationary state at 3000 RPM is reached after 150 s with a generator of 96% efficiency (see Figure 6). The generator connected to the IC engine supplies 24.55 kW of electric energy to the battery. The charge efficiency in a lithium-ion battery is about 99%, according to Battery University [16], and the usable electric energy stabilizes at 24.31 kW.

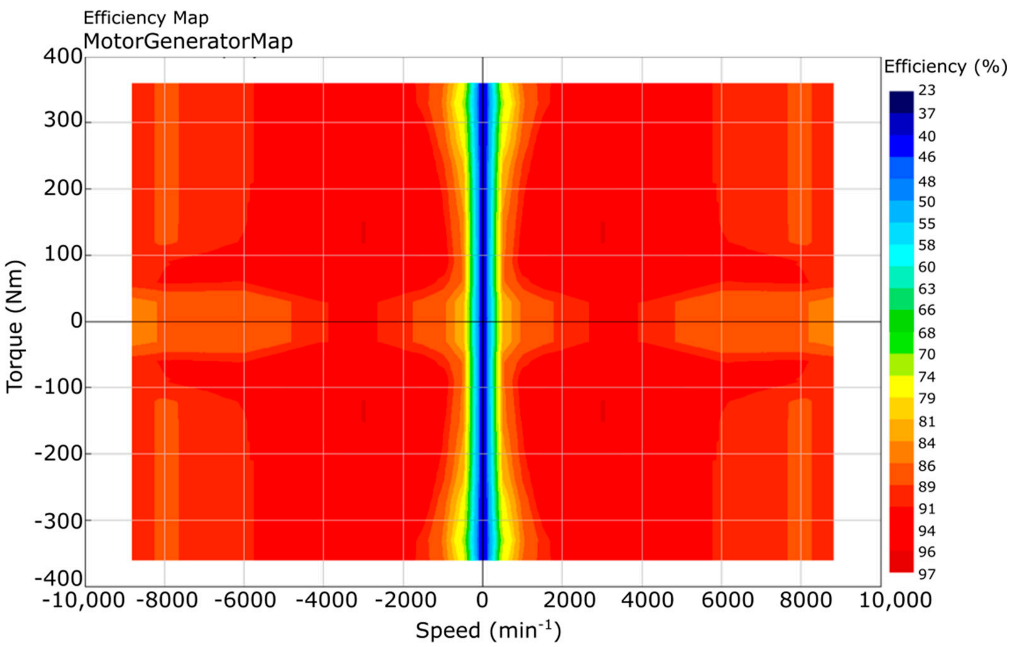

Figure 6. Motor generator map of efficiency based on the engine RPM.

In the case of usable heat energy, the efficiency of HX must be defined. Shell and tube HXs are typically deployed to withdraw heat from an exhaust pipe system and were also used in this study. Exhaust temperatures at the inlet into the HX and at the outlet of the HX are depicted in Figure 7a. When the engine stationary state is reached, the inlet exhaust temperature stabilizes at 612 °C. When the outlet exhaust temperature is dependent on the condensation of exhaust gases, it is selected to be 120 °C to prevent corrosion of the HX. After some time, the exhaust temperature at the HX outlet starts to rise due to the warmer water in the water tank circuit, but the outlet temperature does not exceed 135 °C. The average water temperature in the heat storage of 4000 L volume is depicted in Figure 7b. The efficiency of the HX connected to the exhaust pipe is approximately the same over the whole process, with a value of 90.4%. Based on the results from the energy balance calculation and with the known HX efficiency, usable exhaust heat energy is around 26 kW. The other portion of the heat energy can be supplied from the engine-cooling system. The heat transfer from the engine jacket accounts for 12.5 kW, while some energy is lost due to the heat withdrawal from the pipe cooling system. The overall usable waste heat energy is around 38.5 kW. The whole system efficiency is lower at the start against the efficiency in the stationary state at 3000 RPM, but in terms of working for 1–2 h continuously, the losses can be neglected.

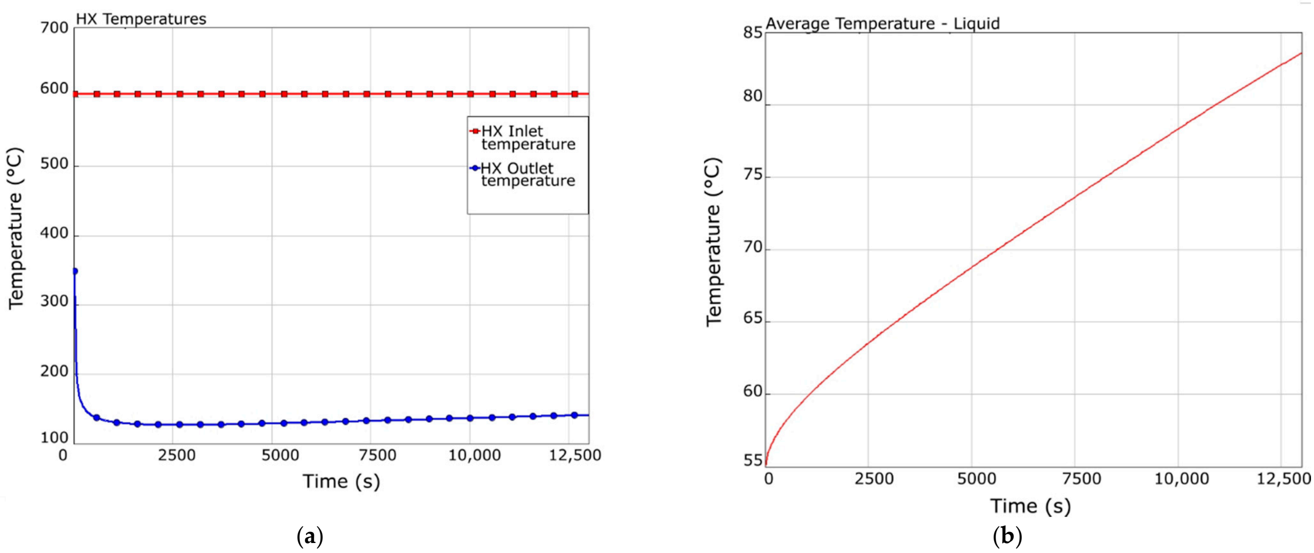

Figure 7. (**a**) Exhaust inlet and outlet temperatures into the heat exchanger (HX); (**b**) average temperature of water in the heat energy storage.

4. Determination of Engine Service Life

When determining the service life of an engine that is used as a stationary engine for CHP, it is necessary to take into account the time until engine overhaul. However, an IC engine in a vehicle operates stationary only for a short period of time and most of the time is exposed to dynamic states. To be able to at least partially cover these events, it is possible to use the parameters of the Worldwide Harmonized Light Vehicle Test Procedure (WLTP) homologation test [17]. The WLTP is a real driving data test that has better matches with on-road performance than the older New European driving cycle (NEDC) test, which was based on theoretical driving in the 1980s. The WLTP laboratory test is used to measure fuel consumption and provide their CO_2 and pollutant emissions. The WLTP test includes driving modes from city traffic to motorway driving with its transient and stop states based on average speed. Vehicles are divided into different classes based on the ratio of engine power to vehicle weight, with most passenger cars falling into the Worldwide Harmonized Light Vehicle Test Cycle (WLTC) Class 3 [18]. The WLTC Class 3 test cycle parameters are displayed in Table 3.

Table 3. Worldwide Harmonized Light Vehicle Test Cycle (WLTC) Class 3 test cycle parameters.

Regime	Low	Medium	High	Extra High	Total
Duration (s)	589	433	455	323	1800
Stop duration (s)	150	49	31	8	235
Distance (m)	3095	4756	7162	8254	23,266
Number of stops (%)	26.5	11.1	6.8	2.2	13.4
Maximum speed (km/h)	56.5	76.6	97.4	131.3	
Average speed without stops (km/h)	25.3	44.5	60.7	94.0	53.5
Average speed with stops (km/h)	18.9	39.4	56.5	91.7	46.5

As this is a homologation test of the entire vehicle, it is also necessary to know the parameters of the whole powertrain. Parameters such as gear ratio and transfer efficiency are set for the Skoda CITIGO vehicle, where the IC engine, 1.0 L MPI CNG, is used, and these parameters are depicted in Table 4.

Table 4. Skoda CITIGO transmission parameters.

Gear	Gear Ratio (-)	Transfer Efficiency (-)
1	3.64	0.98
2	1.96	0.98
3	1.21	0.98
4	0.76	0.97
Final gear	4.167	

The relative distances traveled in each mode are calculated for the engine overhaul set to 100,000 km, and the obtained values of the total mileage run in the individual regimes are shown in Table 5. Based on the external performance of the IC engine depicted in Figure 3, the ideal constant operating speed of the CHP is set to $n_{CHP} = 3000$ RPM.

Table 5. Total mileage in individual regimes.

Regime	Distance (km)
Low	13,302
Medium	20,441
High	30,782
Extra High	35,475

It is further necessary to convert the engine speed n_{CHP} (RPM) to the crankshaft angular velocity ω_E (rad/s)

$$\omega_E = \frac{2\pi n_{CHP}}{60} \quad (2)$$

A conventional multiplate clutch that achieves high transmission efficiency of $\eta_{clutch} = 0.98$ is considered. The rotational speed of the shaft at the input to the gearbox is equal to:

$$\omega_{shaftIN} = \omega_E \eta_{clutch} \quad (3)$$

The speed at the output of the gearbox depends on the selected gear and the efficiency of the gear according to the equation.

$$\omega_{shaftOUT} = \frac{\omega_{shaftIN}}{i_{gear}} \eta_{gear} \quad (4)$$

To obtain the circumferential speed of the vehicle wheel, a correction of angular speed with a final gear (Table 4) must be performed considering the tire rolling radius $r_D = 0.3$ m.

$$v_{wheel} = \frac{\omega_{shaftOUT}}{i_C} r_D \quad (5)$$

The calculated velocities in the individual modes deviate from the WLTP cycle in some cases by up to 13%. This deviation is caused by the constant engine speed, whereas the velocity in the cycle is averaged, and the ride itself contains more dynamic states. However, these values are sufficient for a basic estimation of engine life. Due to the known velocity in individual modes, it is possible to find out the time required to cover the distance (Table 6).

Table 6. Calculated velocity and time in individual regimes.

Regime	Circumferential Velocity (km/h)	Time (h)
Low	21.48	619.18
Medium	39.90	512.34
High	64.63	476.30
Extra High	85.00	417.63

The hourly life of the engine in total, determined as the sum of the given times in Table 6, for the selected overhaul at distance $d_{GO} = 100,000$ km is:

$$t_{GO} = \sum_{i=1}^{n} t_i = 2025.18 \text{ h} \quad (6)$$

For the CHP operating 1–2 h per day, the service life of such an engine offers 3–5 years until a service repair is needed, whereas conventional CHP is serviced yearly and costs a great amount of money.

5. Discussion

CHP units are great energy savers, but in the case of an off-grid residential system working as the only source of energy, CHP units are not that efficient due to the varying local heat and electric demands throughout the year. In this work, the micro-CHP unit is based on a reciprocating engine, Skoda MPI 1.0 L CNG, available as a worn-out unit. The selection of the engine indeed led to a certain difficulty in matching optimal heat energy demands. Due to the engine's high energy potential, for the use in a large, detached house, it must operate only 1 to 2 h a day, which makes the optimization of using the energy throughout the day unnecessary. The energy is always stored and then taken from the water heat energy storage and battery pack. This type of energy consumption results in reduced system efficiency due to the heat loss in the piping systems and from the water tank storage over time. The energy leakage from the 4000 L tank at 80 °C is around 2.4 kWh per day. This is only a fragment of the heat energy potential accumulated in the water heat storage, but it inherently contributes to the overall inefficiency of the system. The electric energy stored in the battery accumulator is, on the other hand, assumed without any losses, maintaining the surroundings of batteries in prescribed temperatures with a proper ventilation system. Nevertheless, the efficiency of battery charging and discharging should be taken into account, according to [19].

For proper system setups and considering requirements for net-zero CO_2 emissions, systems are usually supplemented with sun-utilizing devices. These include photovoltaic panels that can process greenhouse-free energy from the sun. Photovoltaic panels can supply electric energy, especially during hot summer days, when there is no demand for heat energy, and produce the required portion of electrical energy without excess heat energy generation. Another component for higher overall energy system efficiency is an absorption chiller. Absorption chillers rely on heat energy to chill water, so they make a perfect combination with CHP systems during summer periods [20]. The use of these additional components significantly reduces the CHP operation time and contributes to annual system efficiency while minimizing the overall impact on the environment as the generation of electricity is reduced. The problem with these additional components is their initial cost, but from a long-term point of view, a reasonable return on investment is expected as the components can work without any major services.

For electric energy accumulation, the price of battery units is decreasing owing to increasing order size, growth in battery electric vehicle sales, and the continued penetration of high-energy-density cathodes. However, in 2020, according to TechVision, only 5% of Li-ion batteries are being recycled, which leaves 95% of these batteries unused. Until the closed-loop battery life cycle works on a regular basis, the use of aged EV battery packs is a way to decrease the footprint and provides a cheap option for residential energy accumulation as investments in new batteries are currently quite expensive. Battery packs from firstly developed EVs are reaching the end of their life cycle and thus offer utilization in other sectors that were initially designed. The possibility is presented approximately for 10–15 years, according to [21], until the time when the packs will be reused by companies as additional electric storage or the material can be easily recycled. According to the latest forecast from Bloomberg New Energy Finance, in 2010, the average price was 1100 USD/kWh. In 2019, the price fell to 156 USD/kWh, which is an 87% price drop, and in 2024, the price is expected to be 100 USD/kWh [22]. Nevertheless, while vehicle batteries are usually worn out at 80% of their battery capacity [21] and need to be ejected and recycled, an opportunity is offered for the second life of the battery for energy accumulation purposes in residential houses. It was proposed that the Tesla Model S battery (Li-ion 18,650 cells), with a maximum pack capacity of 85 kWh, can be used for this case of the CHP system and offer enough electricity accumulation to run the house for a few days in the case of CHP unit failure.

The overall economic investments in the case of aged components amount to approximately USD 4000 for the battery pack and USD 3000 for the IC engine CHP. The price for water tank storage is assumed to be USD 4000 for a new component. As discussed earlier, due to the current lack of an insufficient recycling procedure for Li-ion batteries and a great number of worn-out EV battery packs available, the initial investments are minor, apart from newly designed components for residential purposes. In terms of using newly developed CHPs and EV batteries, the approximate price reaches around USD 16,000 for the CHP unit and USD 20,000 for battery storage (20 kWh of accumulation capacity). In the case of standalone residential houses, where no electricity network distribution is implemented, a CNG-operating CHP is the only choice. Inseparably, components such as housing, fittings, and pipes are not compared, and the price in each approach will be the same.

6. Conclusions

In this work, the use of a CHP unit based on the IC engine, Skoda MPI 1.0 L CNG, was described. From an economical point of view, this paper proposes another perspective for the utilization of aged components to provide them a second life for different purposes than they were initially designed. The energy balance of usable heat and electric energy was calculated according to GT-SUITE models with a heat-to-electric ratio of 1.6:1. The service life of the engine based on the WLTP was calculated, and the results gave 2025 h of operation. In a large, detached house, with a daily average run of the engine for about 2(1) h, the engine operation is expected to last for three to five years without major service repairs. The obtained results give a satisfying conclusion about whether or not to use the vehicle engine in the residential sector as a second life of the component. This approach will inherently save huge initial investments in new components and will particularly produce significantly fewer greenhouse gases. The emissions from the recycling of an old engine or battery unit and the production of new components reduce an enormous amount of greenhouse gases. The aged components such as the engine and battery pack will naturally exhibit lower power and capacity against new units, but in the case of oversized units, such as the proposed engine and vehicle battery, these will not affect the overall system reliability. Furthermore, the problem of possible engine breakdown or unexpected events, e.g., the 2021 Texas power crisis, are handled with oversized storage units that can provide a continuous energy supply for several days. Therefore, the approach of using the aged components mentioned in this article will, unfortunately, offer slightly less system efficiency, but on the other hand, with additional units that can alleviate energy requirements during summer periods, they can offer the promising future of low-cost standalone and environmentally friendly options. The findings of this article can be summarized as follows:

- The reconstruction of the ICE from ordinary vehicles available from scrap yards to stationary CHP units with the calculated model, which offers huge energy potential in residential applications, is outlined.
- Economical savings in terms of initial investments into the standalone system, with a 30–40% cost compared to OEM (CHP and battery storage), together with the discussion about the price of electric and thermal energy from the grid compared to the price per kW generated by the CHP, are shown.
- The utilization of oversized units without any additional investments can withstand unexpected events of breakdowns or natural disasters for several days.

- The reduction in greenhouse gas emissions while enabling the second life of the aged, withdrawn components with great energy potential to offer.

Proposals about higher system efficiency were discussed, and future work will concentrate on the more sophisticated design of the standalone energy system to be more efficient, together with solar energy, even with aged units available on the market.

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