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The Value of "Vehicle to Grid" Integration into Warehouse Logistics Management – Case of Slovenian Retailer

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Wide-scale application photovoltaic energy sources for electricity production purposes is quite a challenge in Slovenia. The nature of sun is unpredictable, and the Slovenian National Grid has no significant storage opportunities today – if the V2G (vehicle-to-grid) solutions could be competitive in the near future we could prepare for the special circumstances: the batteries of electrically driven forklifts could provide attractive storage functions for renewable electricity storage. The following paper presents an overview of some "environmental background approaches" to show the complexity of this innovative system and to show the value of V2G technology and its application in warehouse logistics.

Key words: Renewable electricity, photovoltaics, warehouse logistics management, V2G

1 Introduction

This paper builds upon the paper "Vehicle-to-grid integration in warehouse logistics (V2G): showing benefits from using it". This paper is also attempting to quantitatively place vehicle-to-grid within the existing warehouse electric system and presents one of the possible models of implementation. We begin this paper with a section that explains the policy background of using renewable energy sources and aim to show possible variations of using electric vehicles (EV) together with V2G. The second part of the paper features calculations of the value of V2G technology and shows how this could really work (in a model) in warehouse logistics.

2 Background policy of renewable energy sources

Climate change and being aware of the fact that natural resources are not renewable calls all agents of global community to think radically about the future of the development and guidelines of strategy design of energy policy. The European Union (EU) is thus dealing with the issue of designing common guidelines in the field of energy policy. EU's main objective is the 20 – 20 – 20 goal which is to be achieved by 2020, i.e. 20 percent refers to reduction of greenhouse gas emissions, 20 percent presents the share of renewable resources aimed for use and 20 percent are to present the reserves for future energy demand at the EU-level (Brown et al., 2008). The average percentage of renewable energy resources in the EU concerning the entire energy use currently lies at 8.5 percent (EU, 2008). Sweden appears to be the best role model in this respect, as it creates 39 percent of energy from renewable energy resources, whereas the latter are practically not used on the island of Malta. In the EU, transport using renewable energy resources incurs 30 million Euros and accounts for around 350 thousand jobs. Should this percentage increase to 20 percent, the number of jobs will have increased to nearly one million by 2020. The use of renewable resources of 20 percent would save from 600 to 900 million tonnes of CO_2 per year; the use of fossil fuels however, would decrease by 200 to 300 millions of tonnes.

The effort to protect the environment we live in and depend on has become the prime concern of contemporary civilization. The current state of the environment is nevertheless inadequate. This can be seen from statistical data on patents for the clean environment in one of the largest polluting countries, the United States. The findings have shown that the number of environmentally-oriented registered patents is decreasing compared to other patents (Knez, Rosi, Sternad and Bajor 2009).

Transportation and logistics are responsible for climate change as they produce greenhouse-gases and contribute

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in the increasing share of fossil fuels (oil) in global energy consumption. The world uses more and more oil. Despite the fact that traction engines are becoming more and more modern and efficient, oil and fossil fuels still have a number of harmful side effects on the nature, where a number of harmful substances can be found in the air, such as carbon monoxide, nitrogen substances and other producers of smog. Carbon dioxide, which causes global warming, is especially disputed. Next generation traction engines should therefore be less wasteful, environmentally friendlier and more accessible and of course more feasible from the economic viewpoint. This is also the modern challenge the car industry is facing (Knez, Rosi, Sternad and Bajor, 2009.)

On the road towards green logistics a lot depends on appropriate AFV-s (alternative fuel vehicles). The vehicle of the near future is the ICE-Hybrid (ICE – internal combustion engine); it will have become the dominant vehicle platform by the year 2020. There have historically been six major barriers to AFV success (Romm, 2006): high first cost for vehicle, onboard fuel storage issues (i.e. limited range), safety and liability concerns, high fueling cost (compared to gasoline), limited fuel stations ("chicken and egg" problem), improvements in the competition (better, cleaner gasoline vehicles). All AFV pathways require technology advances and strong government action to succeed.

The superiority of electricity-driven vehicles (trains, trams, trolleys, forklifts (Kempton and Tomić, 2005)) is widely accepted, both in their performance and for their environmental impact. Apart from the electricity-driven vehicles, the infrastructure for their use is also rapidly developing, such as chargers and battery systems, smart parking and charging stations.

The green energy sources alone are not able to provide all the energy required. To this end, the cooperation between the local green sources and the traditional electricity supply is crucial. The integration of transportation and conventional electrical energy demand should be analyzed, due to the fact that feasibility studies for these systems and structures have a lot of dimensions (tariff-system for electricity, security of supply, the price of the missing energy, frequency of fault events, etc.), and market forces are not what drives sustainable economic development (Foldesi et al., 2010).

3 V2G concept in warehouse logistics

The vehicle-to-grid (V2G) concept is one of the attractive ideas to synergize the electricity and the transportation sector. This concept with pure electric and hybrid-electric vehicles (which are capable to connect to the grid and load/unload electrical energy) could help to better manage electricity resources. Moreover, it empowers vehicle owners to earn money by selling power back to the grid when parking, depending on the current fuel- and electricity-prices. On average, vehicles in the US spend only 4–5% of the day on the road, at least 90% of personal vehicles remain unused (in parking lots or garages) even during peak traffic hours (Tomić and Kempton, 2007).

Within the United States alone (Rydzewski, 2009), there are currently some 230 million gasoline-powered cars, sport utility vehicles (SUVs) and light trucks, which, if converted to or replaced with a combination of plug-in hybrids and all-electric vehicles, could have increased the power capacity of all electricity generation in the country by 20-fold. This large potential power source has great value. When a V2G-enabled

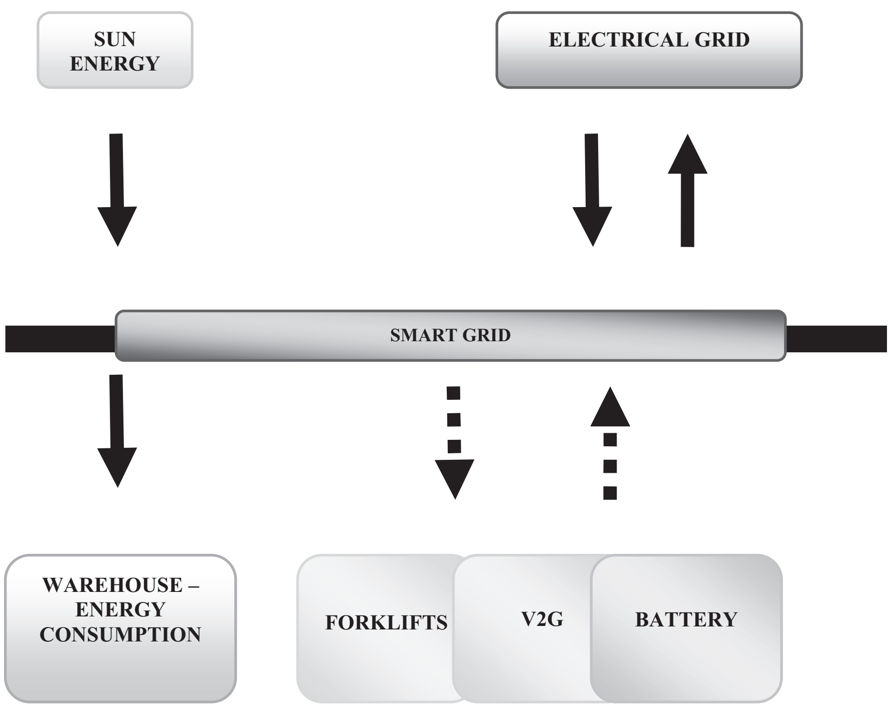

Fig.1. V2G integration in warehouse energy management

vehicle is tied into the electric grid via a power connection, the vehicle's instantly-responsible electric storage system can be directed by a wireless communication device to deliver power services to the region. These power services help to stabilize the electric grid, significantly enhance the capabilities of renewable wind and solar generation, and provide many other value-added services to the community.

V2G further provides an opportunity to improve the reliability of the electric grid. The vehicles are typically parked where people use power – at home and at work. Placement of the vehicles on the grid in this manner makes the power supply a „distributed generation" tool for localized storage and use. When the grid fails, the cars are ready to get back-up power supply. Moreover, V2G creates an opportunity for the vehicles to become revenue-producing assets, as opposed to liabilities that lose value year after year. The V2G-equipped vehicles participate in specific power markets in return for a fee. Several variables affect the income potential, including the size of the battery pack, the type of power service, the hours-per-day the car is parked and plugged in, and the market rate, or value of the service. Couple the above opportunities with a cleaner environment and reduced dependence on imported petroleum-based fuels, and V2G is a win-win for everyone (Rydzewsky, 2009).

3.1 V2G integration in warehouse – a case of Slovenian model

For our research, a central warehouse with mixed goods from Slovenian largest retailer Mercator d.d. was investigated. The warehouse is located in the centre of Ljubljana and has three storages. The possibilities for building a photovoltaic electric plant were calculated for the flat roof of the warehouse with size of 600m^2. Calculations were made from the viewpoint of solar energy use. Figure 1 presents a potential model of integration of forklift and V2G (which use solar energy produced on the warehouse roof) into a common energy system:

Mercator uses 128 electric forklifts (Table 1), with an average battery capacity of 17.2kWh per vehicle, amounting to approximately 2.2MWh. The forklifts are used for goods commissioning and other warehouse operations from 6 am till 10 pm, 5 days per week. During weekends, vehicles are parked at the chargers. Each vehicle has its own schedule of operations, but on average it is used 11 hours per day. That means that 30% of working time vehicles are parked at the chargers.

Forklifts can now use lithium ion batteries to get V2G plug-ins, either as original equipment or as supplementary aftermarket power modules. Lightweight lithium ion batteries have greater power density and are capable of thousands of charge cycles, making them suited to the grid's fluctuating need for power (Morrison, 2008).

Table 1: Forklifts characteristics (Jungheinrich, 2008)

Vehicle characteristics	
Battery type	lithium ion
Energy stored (kWh)	17.2
Maximum depth of discharge (%)	80
Maximum power to motor (kW)	4.5
Max range (km)	100
Battery cycle life (cycles)*	1500
Battery cost OEM (€/kWh)**	220
Replacement labor (h)	8

The photovoltaic (PV) roof system will feed the grid directly or charge the vehicle batteries. The vehicles will make money selling power into the grid during high-load conditions by responding to market price signals above. The system (smart grid[1]) will monitor vehicle battery charge, solar output and local electric system demand.

With a real-time controller we can respond to price signals from the electric grid spot market. When the grid calls for more power, we would feed in the available surplus from the forklifts batteries and the PV charging system, thus helping to reduce spot prices and satisfy the system's need for power. A key aspect of achieving the promise of V2G systems and a renewable electric grid is the ability to implement smart control between the electric grid, user devices, and power sources such as V2G batteries and distributed generation such as PV.

There are two possible scenarios (Knez andBajor, 2010). According to the first – all energy produced by the PV roof is sold to the grid directly and the forklifts are charged from the grid and sell energy back where there is a need for that. According to the second scenario – energy produced by the PV roof is stored in warehouse (forklifts batteries or other storage systems) and sold to the grid or used for local warehouse energy demand (the 2nd scenario will be a subject of our next future research).

4 Methodology of research

The research is divided into two sections. In first section we show the calculation of the energy produced by PV and in the second part we show the calculation and value of our V2G model.

1 The smart grid is made possible by applying sensing, measurement and control devices with two-way communications to electricity production, transmission, distribution and consumption parts of the power grid that communicate information about grid condition to system users, operators and automated devices, making it possible to dynamically respond to changes in grid condition. A smart grid includes an intelligent monitoring system that keeps track of all electricity flowing in the system. It also incorporates the use of superconductive transmission lines for less power loss, as well as the capability of integrating renewable electricity such as solar and wind. When power is least expensive the user can allow the smart grid to turn on selected home appliances such as washing machines or factory processes that can run at arbitrary hours. At peak times it could turn off selected appliances to reduce demand (Wikipedia, 2009).

4.1 Energy from PV

The data were acquired from the Ministry of the Environment and Spatial Planning, the Environmental Agency of the Republic of Slovenia for the period from 2003 to 2009. The measuring spot lies very close to our warehouse. The micro location is important due to its specific features which are present in this part of the city, e.g. the fog and smog. The degree of solar irradiation that reaches planet Earth depends on solar activities, latitude, weather (cloudiness, humidity) and altitude as well as relief shape (Enecom, 2009). Slovenia has latitude of 46˚ north and influences the angle of solar rays, depending on the season, taking into account the axis of the earth of 23.5˚, as can be seen from Figure 2.

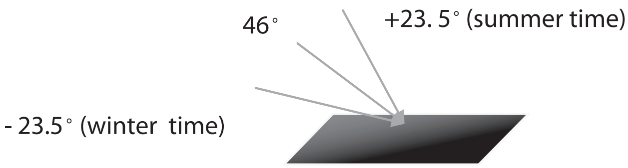

Fig.2. The direction of sun on horizontal surface (angle=0˚).

The latitude of 46˚ reaches the maximum angle on 21 June which is 67.5˚ (90-(46-23.5˚) = 67.5˚. In December, when the days are the shortest, the angle is the smallest. Therefore, the sun reaches the lowest energy values of irradiation, which means that the angle of rays is smallest on 21 December at noon and is only 21.5˚ (Lead, 2009). Regardless of the optimal direction of solar cells that alters throughout the year, the data in this paper refer to the horizontal surface. With the optimal direction of solar cells, that also takes into account the current latitude (based on the horizontal surface) and the direction of the sun, the expected efficiency increases by at least 10 percent.

Slovenia mainly has continental weather and different seasons. Therefore, total volume of solar energy (Figure 3) is smaller than for example in tropical areas and is also unequally distributed throughout the year (Figure 4). In Germany, the irradiation is around 1000kwh/m^2 in subtropical areas it is around 2000 or 2500 kWh/m^2 (Lead, 2009). Slovenia lies ahead of Germany, as it has around 1250kW/m^2.

The research further aims to calculate solar energy and thus focus on limit values of solar irradiation (minimum and maximum) throughout the entire year. Focus was on year 2009. Moreover, we further took into account the data for December as the weakest month and July as the strongest month regarding the distribution of solar energy.

Efficiency of solar modules, which today are available on the market, ranges between 8 and 20 percent In our research, electric characteristics of semi-crystal silicon photovoltaic modules of the company Bisol d.o.o. from Slovenia were taken into account, where the average efficiency of cell transformations (at temperatures of 25˚C and 44˚C) is 14 percent.

Figure 4 gives values of produced energy multiplied by the efficiency of the chosen solar cells. These values then present electric power that could be used. The values naturally refer to a square meter of horizontal surface.

Mercator has a flat roof with size of 600m^2, so if we miltiply this daily numbers by the size of the roof we get the data, shown in the Figure below.

The figure 5 shows that an average production of sun energy per day in July is 510kWh and an average sun energy produced in December is 53kWh, which shows that if we would use this energy for warehouse energy needs, this amount of energy in July covers 5% of daily energy demand and in December just 0.6%. But due to the policy of electrical energy system in Slovenia it is better to sell all produced energy to the local grid, because the prices are subsidized from the government. But latter in our research the revenue from energy produced on the Mercator roof will take a part of our research.

4.2 Value of V2G integration in warehouse system

The economic viability of V2G depends critically on the cost, the forklift owner has, to produce V2G power (Tomić and Kempton, 2007). Eq. (1) is used to calculate the per kWh cost to the battery of forklift owner for providing power to the grid and Eq. (2) is used to calculate cost of battery degradation

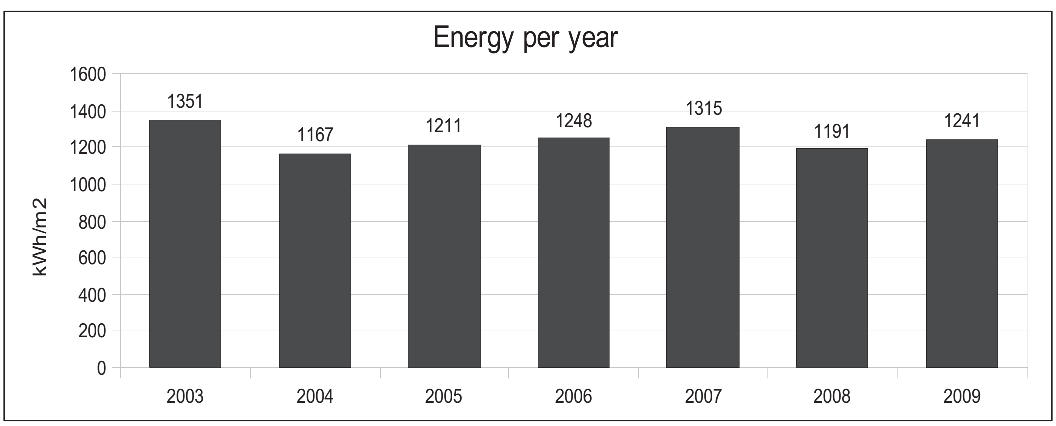

Fig.3. Summary of energy per year in kW/m^2 on horizontal surface (Jereb and Knez, 2010)

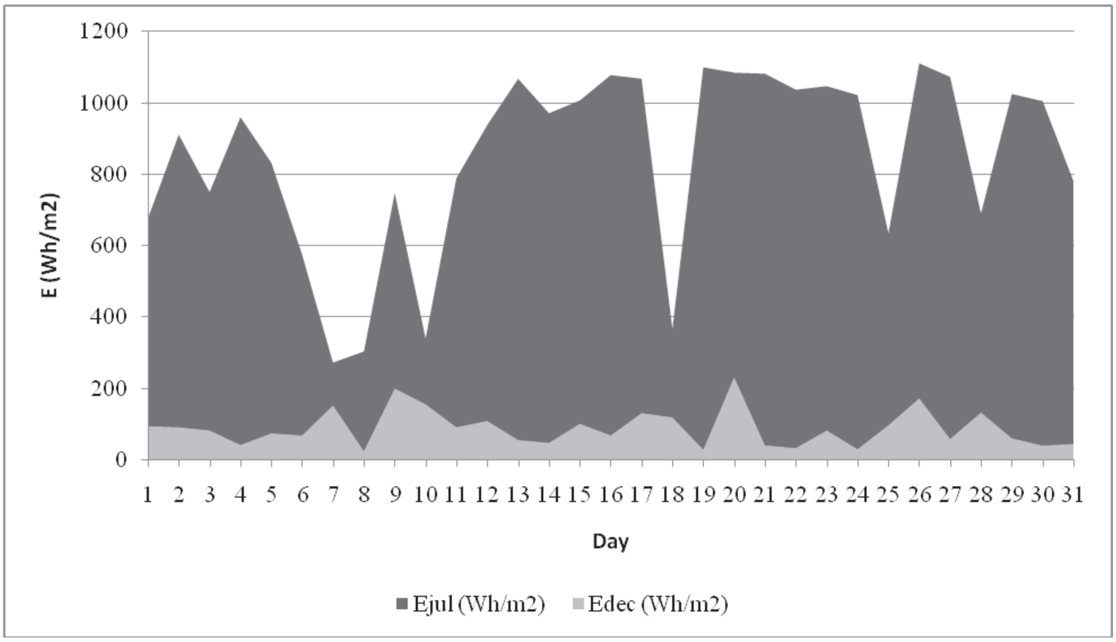

Figure 4: Energy distribution (per day/m²) in July and December 2009 (Jereb and Knez, 2010)

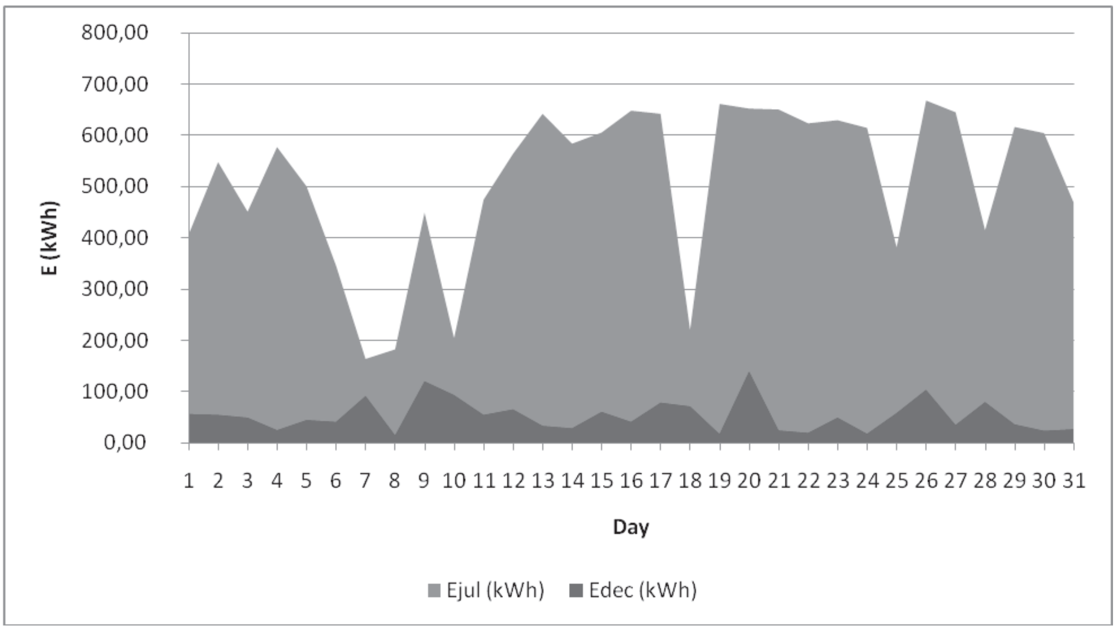

Figure 5: Energy distribution (per day/roof) in July and December 2009 (Jereb and Knez, 2010)

$$c_{en} = \frac{c_{pe}}{\eta_{conv}} + c_d \tag{1}$$

$$c_d = \frac{c_{bat}}{L_{ET}} = \frac{(E_s c_b) + (c_1 t_1)}{L_c E_s DoD} \tag{2}$$

where *cpe* is the cost of purchased electricity for recharging in €/KWh, *cd* cost of battery degradation in €/KWh calculated as shown in Eq (2), *ŋconv* the conversion efficiency of fuel or electricity (in this case it is the two way electrical efficiency (electricity to battery storage and back to the electricity), which for a more efficient than average battery is 0.73, *cbat* the battery replacement cost in € (capital and labor costs), *LET* the battery lifetime energy throughput for a participant cycling regime in kWh, *Es* the total energy storage of the battery in kWh, *cb* cost of battery replacement in €/kWh, *c1* the cost of labor in €/h, *t1* labor time required for battery replacement, and *Lc* is battery lifetime in cycles.

The other cost component of delivering V2G power is the fixed cost, expressed as annualized capital cost *cac* for additional equipment required for V2G (Tomić and Kempton, 2007).

$$c_{ac} = c_c \times CFR = c_c \times \frac{d}{1-(1+d)^{-n}} \quad (3)$$

where *cc* is the capital cost (the one time investment) in €, *d* the discount rate and *n* is the time during which investment is amortized in years. AC propulsion, Inc. (2007) has designed a power electronics system that allows charging from and discharging to the grid, which fixed cost is around 300€ (*cpes*). Further equipment we need is on-board metering of electrical flow for billing purposes, which costs around €40 (*cms*) and a wireless system installed in production scale is estimated around €75 (*cws*). The total capital cost ($c_c = c_{pes} + c_{ms} + c_{ws}$) is €415. According to Eq.(3) the capital annualized cost using a discount rate of 10% over a period of 10 years is approx. €42 per year, per forklift.

When the forklift is providing only regulation down, the capital cost is lower. In this case, power flows only from the grid to the forklift and the forklift would require only the on-board metering device (€40) and the wireless interconnection (€75). The incremental capital cost is only €115 and the annualized cost (using Eq. (3)) is approx. €12 per vehicle.

The electrical power capacity available for V2G is determined by two factors (Tomić, Kempton, 2007): (a) the limitation of the electrical circuit where the forklift is connected and (b) the stored energy in the battery divided by the time it is used.

The electrical circuit limit is computed from the circuit's ampere capacity (A), multiplied by the circuit's voltage (V). This term we call the power capacity of the line or Pline (Eq.4).

$$P_{line} = I \times U = 50A \times 220V = 11kW \quad (4)$$

Based on practical limits on typical home and commercial circuits, here we use 15kW as the *Pline* limit. The limit imposed on the electrical power capacity for V2G by the forklift (*Pforklift*) is a function of the energy stored onboard (i.e. in the batteries), the dispatch time needed, and the driver's requirement for driving range. The formula for calculating *Pforklift*

for battery EDVs is shown in Eq. (5):

$$P_{forklift} = \frac{(E_s DoD - d_d + d_{rb} / \eta_{forklift})\eta_{inv}}{t_{disp}} \quad (5)$$

where *Pveh* is power capacity in kW, *Es* the stored energy available in kWh, *DoD* the maximum depth of discharge of the battery, usually 80% for NiMH and 100% for Li-Ion batteries, *dd* the distance driven in km since the battery was full, *ηforklift* the forklift driving efficiency in km/kWh, *ηinv* the efficiency of the inverter and other power electronics (dimensionless) with a value of 0.93 (Tomić, Kempton, 2007), and *tdisp* is the dispatch time in h. The dispatch time will be a fraction of the plugged-in time. The electrical power capacity for regulation is determined by the limits imposed by *Pline* rather than the *Pveh*. When V2G is used for regulation *Pveh* is a much higher value than *Pline* due to short instantaneous dispatch time (usually on the order of 1–4 min).

When the vehicle is providing regulation down only (power flowing from grid to vehicle), the power capacity will be defined by wiring and the electronics (*Pline*), but storage capacity of the battery and *DoD* will determine how long the vehicle will be plugged-in (*tplug*) before the battery is full. Referring to Tomić and Kempton's (2007) calculations and equations rearranging we arrive at *tplug* (Eq. 6)

$$t_{plug} = \frac{E_s DoD \eta_{charger}}{P_{line} R_{d-c}} \quad (6)$$

where *ηcharger* is the efficiency of the charger, or efficiency of line AC to battery charge, with a value of 0.93. In regulation-down only mode, we assume that *DoD* is 50% at the start so after the battery is fully charged, the vehicle will not be available to provide regulation down.

Using Eqs. (1)–(3) and cost of purchased electricity of € 0.066/kWh we calculate the cost of energy for regulation (*cen*). Cost of energy for regulation up and down is € 0.235/kWh and the annualized capital cost per vehicle is € 41.5.

We assume that each of the forklift fleet would be plugged in for 7 hours (*tplug*) and *DoD* would be 80%, which means that each forklift could miss out on 20% of the energy stored in the battery. From that we can calculate the annual revenue of each forklift using Eq. (7)

$$r_{Reg-up} = (p_{cap} P t_{plug}) + (p_{el} P t_{plug} R_{d-c}) \quad (7)$$

where the *pcap* is the capacity price in €/kwh, *tplug* the amount of time in hours the forklift is plugged in, *pel* the market (selling) price of electricity (€/kWh) and *P* is the power of the forklift in kW.

The term (*Rd-c*) is the dispatch to contract ratio, which in combination with *tplug* defines the dispatch of V2G power (Tomić and Kempton, 2007). The *Rd-c* is defined by Eq. (8)

$$R_{d-c} = \frac{E_{disp}}{P_{cont} t_{cont}} = \frac{E_{disp}}{P t_{plug}} \quad (8)$$

where *Edisp* is the energy of the battery in kWh, *P* is the power of the forklift motor in kW and *tplug* is the time in hours forklift is plugged in.

4.3 Results of research

Using the equations above, we calculate the annual revenue and cost for the regulation of each forklift, from which the net profit of whole forklift fleet is calculated, which amounts to € 6371 per month.

Considering the different scenarios of our model, the first scenario was chosen, which presents the current situation and includes all costs for electrical energy in a warehouse. Due to all calculations and facts we have made and described in our research, according to the first scenario up to 33% of costs could have been saved per month for electrical energy during summer time and up to 22% during winter time.

According to the last result, we can also argue that by purchasing less electrical energy from the grid we are becoming more environmentally friendly, because our carbon dioxide footprint is thus reduced. One kWh of electrical energy in Slovenia is equal to 0,618kg CO_2, what in our research means approx. 9.7 tones (-4.6%) of CO2 less in summer time and 1.02 tones (- 0.5%) in winter time.

5 Conclusion

The paper presented the use of V2G power from battery electric vehicles (forklifts) to provide power into the grid responding to market price signals above. Our calculations show that the proposed model (first scenario) is economically feasible.

We are aware of the fact that the technical side includes barriers, such as: the current batteries of forklifts are not designed for that kind of use together with V2G technology, even the battery cycles should be higher, regulation signal from the national grid is a problem, here Smart Grids must be implemented in our electrical systems, not just on the national level but also on the local (company) level, there are no standards for V2G and no mass production of equipment needed for this technology.

From the perspective of the national electric system we can say that V2G is a new source of power, which in the future will play an important role in energy management and will also affect costs of logistics operations in warehouses. The forklift won't be just a machine for loading and unloading, but also a battery for renewable energy sources and a new source of power, for the local (company) or national grid. It will not only decrease demand for electrical energy from the national grid, but it will also become an additional revenue and make companies more independent and sustainable by fewer lower carbon dioxide footprints.

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Vrednost integracije V2G v logistični management skladišča – primer slovenskega trgovca

Aplikacija fotovoltaike za namene proizvodnje električne energije predstavlja za Slovenijo zelo velik izziv. Sonce kot vir energije je zelo nepredvidljiv, slovensko električno omrežje pa nima večjih možnosti shranjevanja električne energije. Z integracijo tehnološkega koncepta V2G (ang. Vehicle to Grid; slov. Vozilo na Omrežje), bi baterije električnih viličarjev lahko uporabili za shranjevanje energije proizvedene iz sončne energije tar tako povečali zanesljivost elektroenergetskega sistema.
Članek predstavlja tehnološki koncept V2G, njegovo kompleksnost in inovativnost ter možnost integracije v skladiščni energetski management.

Ključne besede: Obnovljivi viri električne energije, Fotovoltaika, skladiščni logistični management, V2G (Vozilo na omrežje)