Outlook of Electricity Procurement Options – Regarding to Key Energy Use and CO₂ Emission Scores in the Car Manufacturing Process

Michael Pritzke
Freiberg University of Mining and Technology
Correspondence: Michael Pritzke
m.pritzke@ingenieur.de
Toghrul Baghirov, Assistant
togrul1988@yahoo.com

Abstract

In an era of increasing globalization and a growing demand for sustainable structures, internationally acting companies face the challenge of adapting their value chain in all business areas. One area is the use of energy and electricity to manufacture goods. Electricity can be purchased or it can be self-supplied in a decentralized manner, in particular from renewable sources by companies themselves. The second option is interesting for companies which want to take a direct influence on their production infrastructure. Technologies for sustainable electricity supply are already highly developed, but the issue of costs remains. For that reason, this paper deals with the current situation of energy and electricity use, which is described in an Energy and Emissions Portfolio of the automotive industry. Using the concept of global Levelized Cost of Electricity and cataloging of expertise best case and worst case scenarios are created and presented in a World Scorecard. The outcomes may contribute to the calculation of electricity procurement options and the creation of decision making basis for this important management task.

Keywords: Levelized Cost of Electricity (LCOE), electricity procurement, energy management, car manufacturing industry

Introduction

The paper begins with a description of a well-established car manufacturing plant and an overview of its energy use and carbon dioxide emissions performance. The car manufacturing industry is represented by BMW as an internationally acting company (Shimokawa, 2010). BMW is considered to be a leader in sustainability management (Dow Jones Sustainability Indexes, 2010). For this reason, the company’s energy management is subject of this paper. Using the concept of an Energy and Emissions Portfolio, calculations are made to identify the costs of energy use for the manufacturing of a completely built vehicle (CBV), car components (CKD) and a semi-knocked down plant (CKD, SKD). The second part of the paper describes several alternative electricity procurement modes. With increasing globalization and a growing importance of sustainable structures, self-supplied electricity from non-conventional energy sources constitutes an interesting option.
The paper concludes with an analysis of the Levelized Cost of Electricity (LCOE) in order to create a so-called World Scorecard of the LCOE of different energy sources and countries. This Scorecard, which allows for regional differences and the dimension of time, can be used to prepare decision making with respect to electricity procurement. The paper presents a future outlook of the LCOE for the years 2010, 2025 and 2035.

1 Description of a well-established Car Manufacturing Plant

This section deals with three important aspects of the automotive industry: the Car Manufacturing Process, Sustainability Management as a part of a company strategy and the Energy and Emissions Portfolio of a well-established car manufacturing plant. In order to understand what is meant by a Sustainability Strategy, the case of the BMW Group is used, since it has been identified as the most sustainable premium automobile manufacturer in the world.

Sustainability Management as a part of the World Automotive Industry

An increasing number of companies publish reports on their environmental, social and economic policies and performance. In doing so, they communicate their best practices for meeting their own strategic objectives and those of society simultaneously. These objectives consist in producing goods and services with least environmental impacts and highest economic and social yields. Best practices encourage investment communities to focus on the degree to which companies are sustainably managed. Energy scarcity and emissions regulations are important drivers for continuous changes in the automotive industry (USAID, 2007):

- Nearly 10% of global carbon dioxide emissions stem from the use of automobiles. Policy makers have a long and endless tradition of tightening emissions limit values of car engines and setting standards for energy efficiency;
- Fossil fuels have experienced and continue to experience unpredictable and volatile prices.

BMW has a long tradition in taking measures to reduce its impact on the environment. The Group is committed to serve customers with environmentally friendly products. It invests large R&D resources in product improvements and in developing new propulsion systems, such as electric power, hybrid power and hydrogen engines. In 2010, the company offered 49 models with EU5 and EU6 emissions standards and nearly 20 models with a CO\textsubscript{2} output of less than 140 g per km. Hence, these cars perform well in terms of taxation. BMW also developed the Mega City Vehicle (MCV), an urban electric car. The main impacts of these developments consist in lower fuel consumption and air pollution emissions (BMW i, 2011) (BMW AG, 2011).

In order to strengthen its position as a sustainable company, the BMW Group is a charter member of the U.S. Environmental Protection Agency’s (EPA) and the U.S. National Environmental Achievement Track, which recognizes companies for their environmental stewardship and performance. It is also listed on the “Dow Jones Sustainability Group Index”, where it was ranked as the world most sustainable car manufacturing company for 2010 (Dow Jones Sustainability Indexes, 2010).

Overview of the Car Manufacturing Process

In Europe, the automotive industry was the key industrial sector in the second part of the twentieth century and nowadays the European market is the most important one (Edelhoff, 2009, p. 3-4). A “car” is referred to as a motor vehicle with at least four wheels, used for the transport of passengers. Nearly 87% of all vehicles produced annually and worldwide are cars with the remaining 13% representing light commercial vehicles and heavy trucks. In 2009, about 51 million cars were produced globally, of which Germany accounted for 11% (Worldometers, 2011). “Production” implies the manufacturing of a completely built vehicle plant (CBV) or completely or semi knocked down plant (CKD, SKD). CKD and SKD are a common practice within the automotive industry. Car manufacturers send knocked down kits to their foreign affiliates or licensees for various reasons, i.e. to avoid import taxes or to receive tax preferences for providing local manufacturing jobs (Miller, Russell R., 2000, p. 281). The lay-out of a car manufacturing plant typically reflects four production stages (Paul Nieuwenhuis, 2003, p. 103-107; James W. Rinehart, 1997, p. 15-22):

- The Press Shop is the unit where steel sheets are pressed into form in order to construct the body parts. It can be an integrated part of a plant but...
body parts can be also supplied from outside. The process is capital-intensive and technologically sophisticated.

- **The Body Shop** is the unit where the pressed car components (parts supplied from outside) are welded together to form bodies. The main welded panels are: chassis, main body, door and white body. This process is highly automated.

- **The Paint Shop** is the unit where the steel bodies are coated in various stages. It is a complex process and the major bottleneck. The process is characterized by the highest demands in terms of energy efficiency and harsh production environment (heat, fouling etc.). It has certain environmental problems, such as air pollution, waste etc.) and it usually requires large amounts for drying and stabilizing coating agents within an acceptable time.

- **Assembly** is the final stage of the production process, where wiring, piping and many other components are fitted to the body. After assembly of engines and transmissions, the car can be put on wheels and can be completely finished. This production process is labour intensive.

Next to these four shops, other auxiliary functions are required. No shop can operate in the absence of logistics. Furthermore, quality management is vital and becomes more important with rising flexibility and transformability of the production process (Dashchenko, 2006, p. 403). Lastly, energy, in particular electricity is required for each step within all shops.

### Energy and Emissions Portfolio of Car Manufacturing Companies

An important way to assess performance in terms of sustainability management consists in a comparison of energy use per produced car across plants and companies. Similarly, this comparison can also be made for \( \text{CO}_2 \) emissions per produced car. The result is known as an Energy and Emissions Portfolio and it can be established for a well-established completely built vehicle (CBV) plant, car components manufacturing plant and completely or semi-knocked down (CKD, SKD) plant. A well-established plant has best practice performance and it can be used to assess the options for electricity procurement options. It can also serve as a benchmarking tool for ranking various plants of a company and across companies. At the BMW Regensburg plant, many inputs such as water, and supply materials and outputs such a waste and emissions are also used for screening, but this paper focuses on energy used and emissions of \( \text{CO}_2 \) (BMW Standort Regensburg, 2010). Figure 1.1 presents the Energy and Emission Portfolio of leading car manufacturing companies, including the well-established plant. The purple circle in Figure 2.1 represents the BMW Regensburg plant. It has the lowest \( \text{CO}_2 \) emissions of around 2.2 MWh per produced car of all plants and companies shown. It even outperforms BMW Group in Germany. Not shown, but also worthwhile to mention is the average level of Volatile Organic Compounds (VOC) level which is below 2 kg per produced car, compared to around 5 kg per produced car in Europe.
Figure 1.2 presents the maximum, minimum and average levels of energy consumption for a CBV plant, a car component manufacturing plant and a CKD and a SKD plant (Hahn, Figge, Barkemmeye, & Liesen, 2010). The net calorific value of total energy consumption of the best practice and completely built vehicle plant in 2010 was 368,366 MWh in comparison with an average energy consumption of 420,000 MWh. Car components production plants consume considerably less energy, ranging from 20,000 to 400,000 MWh. For CKD and SKD plants, energy use ranges between 50,000 and 200,000 MWh. The results shown in Figure 2.1 and 2.2 lead to the issue of improvement of company performance at plant and group level in terms of energy use and energy procurement. The next section deals with available options.
Electricity Procurement for Car Manufacturing Plants

Electricity is a good, produced and delivered in four main vertically interdependent steps. These steps include the generation of electricity, its transmission, its distribution and its retailing. Generation is the process of transforming other energy sources into electricity in power plants. Transmission involves the transportation of electricity from power plants to the sub-power-stations along high-voltage cables. Distribution implies the whole-sale of electricity. Retailing includes advertising, branding, contract bundling and billing of electricity for final consumers (Lars Bergman, 1999, p. 29).

There are various options for electricity procurement by industrial customers, but they can all be summarized in three categories (Kals, J, 2010, p. 115):

- Standardized Long Term Contract
- Individually Negotiated Contract
- Energy Exchange Market

A Standardized Long Term Contract provides for supply of all wanted electricity to a customer at any time of the day from an electric utility company, such as – in the case of the BMW Group – E.on AG or Stadtwerke München GmbH (SWM), within standardized terms of delivery at contractually determined prices. An Individually Negotiated Contract is characterized by a customer specific design agreed by an electric utility company according to the customer’s needs. The Energy Exchange Market is not a contract in itself but a market place, like the European Energy Exchange in Leipzig, offering energy according to specific conditions where (anonymous) suppliers sell to (anonymous) customers (Kals, 2010, p. 117). A fourth option can be termed as “Self-Supply of Electricity”. It represents the case of a decentralized electricity infrastructure operated by an industrial company for self-supply. In practice, this way of procurement is not very common, with exceptions such as the BMW Group and the Volkswagen Group (Volkswagen Aktiengesellschaft, 2009) (Southeast CHP Application Center, p. 1-2). Figure 1.3 shows the four options for electricity procurement.

Procurement Model for the well-established Car Manufacturing Plant

Given these four options, the issue of constructing a model for electricity procurement for a well-established CBV plant can be addressed. The model is based upon the well-established Regensburg car manufacturing plant.

Figure 1.4 describes in a Supplier-Input-Process-Output-Customer model the energy flow of the well-established car manufacturing plant. At Customer level, (right hand side of the figure) all process steps and their respective energy needs are shown for a CBV plant and a distinction is made between process energy and facility energy (for the respective buildings).

At Output level energy consumption is shown for each process step as shares of electricity, heat and compressed air and power demand. The highest energy consumption is required for the paint shop. The assembly
and the press shop consume less energy. In order to optimize the energy efficiency in terms of the Energy and Emission Portfolio, measures taken in the paint shop would achieve the highest effect. Depending on these measures, emissions would decrease linearly to the level of energy efficiency.

In the process level, the energy flow is presented as a simplified Sankey diagram. It shows that the largest share of the energy mix of the well-established plant mainly consists of natural gas. This is used in a CHP plant for conversion in electricity and heat. The remainder is procured as electricity procured through an energy exchange market. In total, energy consumption amounts to 360,000 MWh per year. Despite its excellent performance in the energy and emission portfolio, this plant has still options for a more environmentally sustainable infrastructure by increasing decentralized power supply.

![Sankey Diagram](Image 169x48 to 182x63)

Figure 1.4 – Supplier-Input-Process-Output-Customer model of energy flows as a Sankey diagram for the well-established car manufacturing plant (BMW Standort Regensburg, 2010).

### 2 Economic analysis of Procurement Options

#### Levelized Cost of Electricity

The value stream of electricity to users and the costs of generation for suppliers are often described in a known as Levelized Cost of Electricity (Kals, 2010, p. 165). Modelling the concept of LCOE starts with the equalization of the present value of the sum of discounted revenues (on the left-hand side) with the sum of discounted costs (on the right-hand side), as shown in Equation 2.1. The subscript "t" denotes time in which the sale of production or the cost disbursement takes place (International Energy Agency and Nuclear Energy Agency, 2010, p. 34).

\[
P_t = \sum_{t=1}^{n} \frac{E_t}{(1 + r)^t};\]

\[
E_t = \sum_{t=1}^{n} \frac{I_t + O&M_t + F_t + C_t + R_t + D_t + T_t}{(1 + r)^t}\]

Equation 2.1 – Sum of discounted revenues (on the left-hand side) equal to the sum of discounted costs (on the right-hand side)

Equation 2.2 is derived from Equation 3.1 through a simple re-arranging. It shows the equilibrium price of electricity as a function of the discounted LCOE.

\[
P_{\text{electricity}} = \frac{\sum_{t=1}^{n} E_t}{\sum_{t=1}^{n} \frac{E_t}{(1 + r)^t}}
\]

\[
P_{\text{electricity}} = LCOE
\]

Equation 2.2 – Price of electricity set equal to the Levelized Cost of Electricity (LCOE)

In the subsequent calculations, taxes have been excluded for obvious reasons. Furthermore, the focus is on decentralized electricity supply for manufacturing plants and, hence, only the LCOE and not the price of electricity are of concern.

The main objective is to determine the LCOE as the sum of total life time costs, excluding profits. In other words, in Equation 2.1, total discounted revenues are set equal to total discounted costs and there are no excess profits (Fraunhofer Institut für Solare...
Energiesysteme, 2011, p. 7). This implies that Equation 2.1 can be rewritten as Equation 2.3:

\[
LCOE = \frac{\sum_{i=1}^{n} \frac{(I_i + O&M_i + F_i + C_i + R_i + D_i + T_i)}{(1+r)^i}}{\sum_{i=1}^{n} \frac{F_i}{(1+r)^i}}
\]

Equation 2.3 – Levelized Cost of Electricity (LCOE)

Present and future outlook on the Levelized Cost of Electricity

Starting from the theoretical analysis and using current data and estimated future data, the LCOE of 2010 and the estimated LCOE of 2015 and 2035 were generated. The results are shown in so-called World Scorecards, which represent electricity generation costs of various technologies for important car manufacturing and car user countries, such as Germany, USA, Brazil, Russia and China (Julian Marr, 2010, p. 22).

The LCOE are calculated as the present value of the total costs of building and operating an electricity generating plant with a given technology over its financial life time, converted to equal annual payments. These payments are given per kWh on the basis of an assumed appropriate duty cycle.

Figure 2.1 provides the average LCOE for 2010. For each technology, it shows the maximum, minimum and mean values of the LCOE. It can be seen that, for most technologies, Germany, had the highest electricity generating costs of all compared countries. In general, developed countries have higher costs mainly due to high operation and maintenance costs and carbon costs.

The estimation of the future LCOE for the given countries is calculated in line with independent research expert advice, literature study and an average expected increase or decrease of cost categories.

Table 2.1 summarizes the assessment for the future estimation of the cost categories. In the columns the cost categories are listed, the lines respective energy sources and technologies. For instance, the capital costs of coal and gas technologies were considered to be the same as in the reference case of 2010. For the capital costs of electricity generation from solar photovoltaic technology, a decrease has been assumed in line with the decreasing costs of solar photovoltaic cells. Operation and maintenance costs were estimated to increase by 5% for developed countries and by 10% for developing countries until 2025 and by 10% for developed and 20% for developing countries until 2035. Carbon costs were included only for developed countries and were estimated to increase by 100% from the 2010 reference year.

Based on the sources of Table 2.1, Figures 2.2 and Figure 2.3 show the estimated LCOE for 2025 and 2035. Again, for each technology, the maximum, minimum and mean values of the LCOE can be seen.
Table 2.1 – Assessment of cost categories for future estimation

<table>
<thead>
<tr>
<th>Technology</th>
<th>Assumption of future cost estimations according to the literature study</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHP</td>
<td>Year 2025: +5% / +10%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: +10%</td>
</tr>
<tr>
<td></td>
<td>Year 2025: +5% / +10%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: +10%</td>
</tr>
<tr>
<td>Wind Power</td>
<td>Year 2025: -15%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: -20%</td>
</tr>
<tr>
<td></td>
<td>Year 2025: -20%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: -20%</td>
</tr>
<tr>
<td>Biomass Power</td>
<td>Year 2025: -15%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: -20%</td>
</tr>
<tr>
<td></td>
<td>Year 2025: -15%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: -20%</td>
</tr>
<tr>
<td>Solar Photovoltaic</td>
<td>Year 2025: -20%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: -20%</td>
</tr>
<tr>
<td></td>
<td>Year 2025: -20%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: -20%</td>
</tr>
<tr>
<td>Nuclear Power</td>
<td>Year 2025: -15%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: -5% / -10%</td>
</tr>
<tr>
<td></td>
<td>Year 2025: -5% / -10%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: -5% / -10%</td>
</tr>
<tr>
<td></td>
<td>Year 2025: -5% / -10%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>Year 2025: -15%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: -20%</td>
</tr>
<tr>
<td></td>
<td>Year 2025: -20%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: -20%</td>
</tr>
<tr>
<td>Water</td>
<td>Year 2025: +5% / +10%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: +5% / +10%</td>
</tr>
<tr>
<td></td>
<td>Year 2025: +5% / +10%</td>
</tr>
<tr>
<td></td>
<td>Year 2035: +5% / +10%</td>
</tr>
</tbody>
</table>

Year 2025: increase (+) / decrease (-) of costs since 2010 in %
Year 2035: increase (+) / decrease (-) of costs since 2010 in %
-- not considered
3 Conclusion

This paper has focused on two parameters which are important for the evaluation of the performance of car producing plants. They can be described as energy used (measured in MWh per produced unit) and emissions of CO2 (measured in kg per produced unit). Both parameters taken together constitute the so-called Energy and Emissions Portfolio of Car Manufacturing Companies. It could be shown that large differences among car types and companies exist and, hence, that benchmarking becomes a very important and useful tool for Portfolio analysis in order to reduce specific energy use and reduce emissions of CO2. Measures include improved energy efficiency (with an impact on both parameters) and the replacement of fossil by renewable energy sources (having an impact on CO2 emissions only).

Four options for electricity procurement were considered with an explicit mentioning of self-supply of electricity from renewable sources. In order provide information for decision-making about energy procurement options by energy source and geographical locations, the LCOE (Levelized Costs of Electricity) have been computed for 2010 with maximum, minimum and average levels.

Present and future outlook on the Levelized Cost of Electricity

For 2025 and 2035, estimates of these LCOE have been calculated on the basis of specific assumptions. The results have been mapped into so-called World Scorecards. These results are important for the energy management of car manufacturing plants. Given the differences in terms of energy efficiency and emissions of CO2 among car types and car manufacturing plants, benchmarking becomes a very useful tool, in particular for the design and lay-out of new plants or the substantial redesign of existing plants.

For a sustainable energy management, expected increases of energy costs can be encountered by measures to improve energy efficiency and technological innovations may lead to lower specific CO2 emissions, in particular through purchased or self-supplied electricity from renewable sources. Depending on projected LCOE costs, decentralized electricity self-supply technologies may become attractive. In conclusion, it can be stated that the LCOE Scorecard contains important data for strategic energy management in the automotive industry. As a final caveat, one should, however, keep in mind that energy costs and their development over time also depend on political factors and on trend-breaking events. Both are very difficult to predict and their impacts cannot be readily assessed.
References


