Professional MBA
Entrepreneurship & Innovation

SUSTAINABLE ENERGY POLICIES FOR PUBLIC TRANSPORT UTILITIES

A Master's Thesis submitted for the degree of
“Master of Business Administration”

supervised by
Univ.Prof. Dr.rer.pol. Sebastian Kummer

Eva Keuschnig

01431993

Vienna, 21.06.2020

Affidavit

I, **EVA KEUSCHNIG**, hereby declare

1. that I am the sole author of the present Master's Thesis, "SUSTAINABLE ENERGY POLICIES FOR PUBLIC TRANSPORT UTILITIES", 91 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 21.06.2020

Signature

Abstract

The European countries have committed to ambitious climate and energy targets by 2030. Urban mobility consumes a significant part of global energy. One of the challenges is to make public transport in the city energy-efficient and above all with renewable energies. Based on the important role of public transport in the energy consumption of smart cities, this thesis aims to evaluate and describe the most important stakes in public transport according to energy-related topics and to identify the main tasks in the implementation of a sustainable energy policy from the point of view of a public transport company within an urban environment. In this context, energy saving measures and their monitoring are examined.

Based on the review of the literature on energy management and energy efficiency in public transport, a stakeholder analysis and a macroeconomic analysis were carried out. Structured interviews with experts in public transport were conducted and analyzed. These analyzes show that increasing energy efficiency requires a systematic, long-term approach and the use of technical innovations in every mode of transport and its infrastructure, including buildings. The importance of EU legislation is demonstrated by a study of recent developments.

The results also indicate the important role of communication and cooperation in achieving the energy goals and the influence of energy management on the company's brand image. On this basis, a draft energy policy is formulated that describes all relevant tasks in the context of energy management in a public transport company, with a focus on energy costs, the electrification of the bus fleet and the introduction of renewable energy sources in daily operation. A monitoring system with three groups of key performance indicators is proposed to monitor the development of the company's energy efficiency and to achieve the goals of energy policy.

Further research is recommended on the influencing factors of hydrogen economy and advancing digitalization for public transport.

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List of Abbreviations

EnMS	Energy Management System
EP	Energy Policy
PT	Public Transport
HVAC	Heating, Ventilation and Air Conditioning Systems
KPI	Key Performance Indicator
SEU	Significant Energy Use
CVD	Clean Vehicle Directive
DC	Direct Current
GDP	Gross Domestic Product

1 Introduction

The latest data from the World Meteorological Organization shows that levels of heat-trapping greenhouse gases in the atmosphere have reached another new record high in 2019 (WMO, 2020, p. 5). The World Energy Outlook 2019, published by the International Energy Agency states that achieving sustainable development scenario, aiming on holding the rise in global temperatures to well below 2°C, requires rapid and widespread changes across all parts of the energy system. There is no single solution for this transformation, many technologies and fuels will contribute in many economic sectors.

Dr Fatih Birol , IEA Executive Director points out (Birol, 2019)

> "The world urgently needs to put a laser-like focus on bringing down global emissions. This calls for a grand coalition encompassing governments, investors, companies and everyone else who is committed to tackling climate change."

The climate crisis is worsening rapidly and represents one of the most urgent challenges of our time. According to World Bank data, the urban population is increasing. Cities already house half of the world's population but are responsible of two-third of global energy demand. With this urban growth energy consumption and associated levels of greenhouse gas (GHG) emissions are expected to increase. Forecasts predict that approximately 70% of the world's population will live in cities by 2050, being responsible for 80% of global GHG emissions. Urban mobility is an essential tool in the fight against climate change and shall help cities to be resource efficient and low in carbon emission. The development and integration of energy efficient and low carbon urban routes can help to reduce CO2 emission without suspending economic urban development. Reducing energy consumption through efficiency measures has a positive long-term effect and is even improving energy security by decreasing dependence on imported fossil fuels. In addition, energy cost reductions release a city's financial resources that may be utilized to improve or extend mobility services, to create new jobs, improve competitiveness, improve quality of life in cities. (World Bank, 2010)

The International Energy Agency names energy efficiency the first fuel in a sustainable energy system and demands to utilize the world's "first fuel" to its maximum extent. Actually, improvements of energy intensity of the world economy were slowing down and were at only 1,2% in 2018, which is just half of the average rate observed since 2010. This means that new energy efficiency strategies are lacking and that no efforts are being made to reinforce existing measures. (IEA, 2019, p. 3)

Winston, Favaloro and Healy (2020) state that the choices a company makes regarding its energy sourcing and consumption can influence its cost structure. Managing the company's

environmental and climate impacts is a key differentiator for all stakeholders, including consumers. The past understanding was that energy is an omnipresent commodity and there is no way for a company to differentiate itself with this input source. In the past, a consumer was mainly focused on the attributes and the price of a final product, not considering the supply chain beforehand. Today consumers are looking at a product assessing the price as well as the beforehand supply chain when asking themselves if a product was produced social and environmentally friendly. Corporations have realized the new social pressure and are acting accordingly. The social side is becoming a strong force where expectations about a corporate environmental performance are rising. The social pressure to reduce emissions is strong, therefore clean brands and clean offerings can effectively engage stakeholders of all kinds. (Winston, Favaloro, Healy, 2017)

Governments have become very active when it comes to solving the problems connected to climate change as well as putting pressure on companies and consumers involved in carbon emission. Energy efficiency law requires companies of a certain size to reduce energy consumption. If they do not comply with this, they may face penalties or other forms of consequences. Certain companies are obliged to conduct energy management systems. Some are motivated to do so supported by state subsidies, some do it on a voluntary basis to save on energy costs. Today there is really no reason not to monitor and manage company's energy demand.

1.1 Context of the thesis

Energy efficiency measures in transport can take many forms, including managing travel demand to reduce frequency and distance (**avoid**), shifting travel to the most efficient modes (**shift**) as well as system-level and operational efficiency measures and deploying energy-efficient technologies for vehicles and the fuels that drive them (**improve**). However, governments must ensure that the space, resources and support to build and modernize infrastructure and facilities are available (**finance**). (Chen, Ardila-Gomez, Frame, 2017), (UITP, 2020)

Cities with efficient, integrated and accessible public transport systems reduce private car ownership and therefore can significantly reduce energy use und emissions in the city. Public transport is already a low-emission sector that is nonetheless continually innovating to reduce its carbon footprint. This will also support the efforts of the new European Green Deal, aiming for a 90% reduction in transport CO2 emissions by 2050. (European Commission, The European Green Deal, 2019)

In my thesis I aim to study the topic of improvement in public transport systems in large cities with mass transport systems – like metro, trams, and buses – in order to improve the energy consumption needed for moving the passengers as well as to reduce the carbon footprint.

The increase of energy efficiency and use of renewable energies are the core elements of the energy transition. Eschweiler points out that with renewable energies alone the energy consumption cannot be covered at today's level. Therefore, the energy demand must be reduced, and public transport has to contribute to this goal. (Eschweiler, 2014)

The objective of this thesis is to suggest a concept for a sustainable energy policy from the point of view of a public transport company within European cites with the focus on urban rail systems like metro and trams and also bus operation. Trolleybuses, watercraft and cable cars are not analyzed in this thesis.

The term energy management and energy policy are referring to the definition in ISO 50001:2018, Energy management systems.

1.2 Research question

Based on the previous section, the following research question shall be answered by this thesis:

What are the main considerations for energy policy in public transport companies and how can the implementation be monitored?

This central question will be split to following more specific sub-questions:

What are the main tasks in order to pursue a sustainable energy policy?

What are the implementation measures?

How can the implementation be monitored?

1.3 Outline of the Thesis

To answer the research questions the thesis will start with the theory on energy management, focusing on the importance of a well-designed and agreed energy policy – the heart of every energy management.

The next step is to investigate the results and recommendations from published European research projects in the field of energy efficiency and management in the public transport area.

In the practical part of this thesis a stakeholder analysis will be performed to show the involved internal and external parties in energy related issues for a public transport company.

In order to analyze the internal and external business environment of a public transport company on a macro-economic level, a PESTEL analysis is carried out taking into account the European macro environment.

To gain further insight into this topic interviews with experts from public transport will be conducted. The semi-structured interviews will provide insightful information on the approach, motivation and recent topics connected with the energy policy and energy management in a public transport company.

The findings from the interviews will be validated and connected to the previous analyses. The energy related trends and technical innovations in urban transport will be summarized

Finally, the finding of the thesis will be summarized to a viable proposal for a general energy policy for a modern green public transport company.

Additionally, an outlook on further topics to be studied in this field will be provided.

The thesis is structured as follows:

Chapter 1 provides an introduction on this topic and illustrates the motivation behind choosing this particular topic. This chapter also includes the research question and describes the structure of the document.

Chapter 2 introduces the definition of energy management and energy policy following EN 50001. Further the chapter reviews the findings from research projects on energy efficiency measures in public transport and provides an overview about characteristic energy flow in this industry.

Chapter 3 describes the methodology of the research in the thesis including the design of interviews with experts.

Chapter 4 is the practical part of the thesis and contains the results of a shareholder analysis and PESTEL analysis for a public transport company. The results from the interviews will be summarized.

Chapter 5 presents a draft of an energy policy for a public transport company for a modern, green and future-oriented public transport company in a European urban area using all previous chapters. The most relevant activities in an EnMS are outlined and main KPIs introduced.

Chapter 6 addresses the energy management and its successful implementation and summarizes the central steps to drive an energy policy. The final chapter offers an outlook on future topics in this field and the necessity to study them.

2 Theoretical Part

2.1 Added Value of energy management

“What is management? Management is the transformation of resources into output”. (Malik, 2017, p. 33) Malik states that management is not knowledge alone; it is the transformation of knowledge into results. The most central characteristic of our world is that its leading group are people who do not work with their muscles and manual skills, but with their knowledge. Management means action, it means doing, it means accomplishing. The key factor is not behavior, but that very specific type of action that leads to effectiveness and useful results. (Malik, 2017)

Drucker points out that results exist only on the outside of the enterprise, satisfied customers should be the result of a business. Measures to assess the performance of a company are very diverse and reach from market standing, innovation, productivity to development of people, quality and financial results. (Drucker, 2008, p. 10)

Winston, Favaloro and Healy argues that energy is the next evolving driver of competitive advantage for companies and compares energy with the importance of quality issues and IT matters in a firm’s strategy. A strategic approach to energy topics is an opportunity to decrease risk, help resilience, and create new value. (Winston, Favaloro, Healy, 2017)

Nowadays our world can be described as a world of disruption. Bansal states that the speed of change is unprecedented and the changes are broader, and more volatile comparing to what we have experienced so far. Today, businesses have to recognize new challenges and likely answers are different than in the past. Dynamic capabilities - the ability to learn, innovate, and adapt – to deal with this turmoil are tools of survival (Bansal, 2019, p. vii).

Sustainability used to be a side topic in strategic management, now it has become a main issue (Felde, 2019, S. 47). Together with other burning concerns such as waste, carbon footprint and supply chain, energy has become part of enterprise sustainability (Canton, 2019). Within a company energy is a cost driver on one side and has environment aspects on the other side. So, taking action in order to reduce costs and harmful environmental impacts are undoubted benefits for every organization and society (Eccleston et al., 2011, p. xxii). Making better use of its energy-intensive assets can provide rapid benefits for an organization by minimizing the consumption of energy as well as reducing cost and emissions.

A company has to manage different kinds of resources within its reach. For example, human resource management is essential to attract the best people, keep them satisfied and develop their skills. One of the biggest challenges in human resources is the fight for talent, meaning

the competition between corporations for the smartest people with the best skills. Many companies will struggle to win this fight and could lose their competitive force. Canton makes the point that nowadays, a clear commitment of a company to enterprise sustainability is already helpful when it comes to attracting Generation X and the Millennials as the next employee generation. (Canton, 2019)

2.2 Energy management systems (EN 50001)

An energy management system (EnMS) supports organizations in managing their energy use, therefore improving productivity. Energy flows and the associated energy sources are recorded and analyzed. Ideas for improvement are developed and assessed in terms of cost-effectiveness and then implemented. The energy management system helps in the decision-making process for improvements in energy related matters. In the long term, an organization-wide energy policy shall help to support energy targets, create action plans and measure target achievements based on key performance indicators. In addition, energy management influences the organizational and technical processes involving new energy-efficient technologies and reducing energy waste. The EnMS regulates responsibilities for energy-related processes, defines communication procedures and ensures the necessary competencies of the employees involved.

ISO 50001 is built on the management system model of continual improvement Plan -Do - Check -Act. As Howell points out, the four stages are planning and development; implementation; maintaining and sustaining (Howell, 2014, p. 3). This model should incorporate energy management into existing organizational practices.

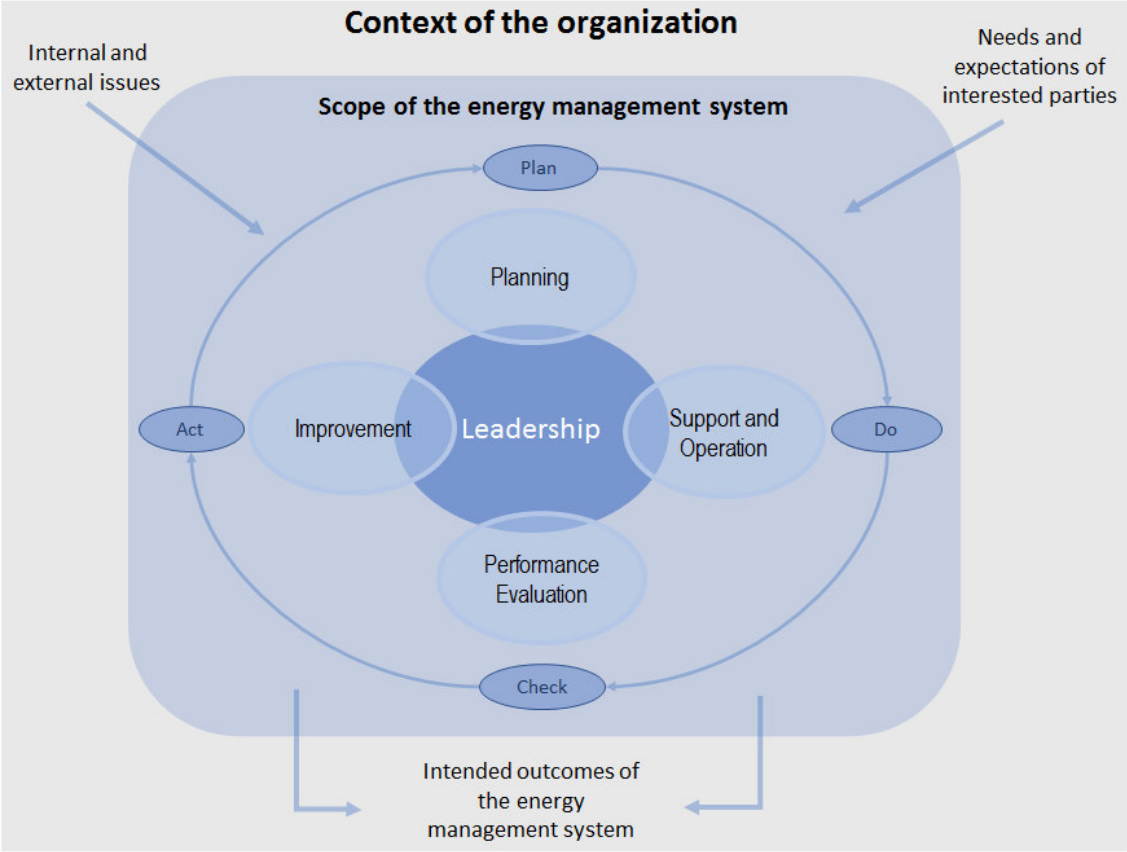

Figure 1: PDCA Continuous Improvement Cycle (ISO 50001, 2018, p. 8)

ISO 50001 supplements the ISO 9001 and 14001 systems of standards for organizational and environmental management. The EnMS is related to ISO 9001 and 14001 in the following manner and it shows that ISO standards have a long tradition in supporting organizations in the context of energy performance:

- ISO 9001—systematic approach towards continual upgrading and managing the quality of products and services provided by an organization.
- ISO 14001— systematic approach towards continual upgrading and managing the environmental compliance and reducing organization's environmental impacts.
- ISO 50001— systematic approach towards continual upgrading and managing organization's use of energy.

The ISO 50001 has been set up to be implemented as an independent separate scheme. It is also possible to combine it with other management systems. The standards apply to all features affecting energy use that can be supervised and influenced by an organization.

ISO 50001 offers an outline of requirements for organizations to:

- "Develop a policy for more efficient use of energy
- Fix targets and objectives to meet the policy

- Use data to better understand and make decisions about energy use
- Measure the results
- Review how well the policy works, and
- Continually improve energy management." (ISO Standards, 2018)

The standard is designed to be universal and flexible enough to be adopted by any organization. The standard describes terms, creates management system specification, offers guidance for implementing the management standards, and demands metrics and measurements for evaluating effectiveness.

According to Eccleston et al., the number of companies and organizations that will sooner or later implement an EnMS around the world is easily in the tens of thousands. The general estimation is that this standard will touch 60% of the world's energy producers and consumers. (Eccleston et al., 2011, p. xxiii)

The ISO 50001 standard mentions expected benefits associated with the installation of an energy management system as follow:

- "Systematic approach to saving energy
- Continuous improvements beyond the introductory phase
- Lowering energy costs and thus increasing competitiveness
- Support climate goals." (Brugger-Gebhardt, Jungblut, 2019, p. 5)

In addition to the benefits that are mentioned above, there are further benefits of adopting an ISO 50001 energy management system, which are mentioned by (Eccleston et al., 2011, p. xxiv):

Prioritize adoption of new technologies and practices.	Support facilities to assess and prioritize the inclusion of innovative energy efficient technologies, including renewable energy systems
Engage top management.	Make energy management a key issue on the highest management level
Formalize organizational energy policy and objectives.	Prepare a basis for informed decisions, initiate respect for energy management policy and anchor energy efficiency thinking in the company
Secure energy supply.	Comprehend the energy risk and classify areas of the business that are most at risk for changes in energy supplies and costs
Drive Innovation	Advance chances for innovative products and services in the climate friendly economy for the next generations
Transparency and communication.	Encourage transparency and enable communication in energy related topics

Table 1 Table Benefits of adopting ISO 50001 (Eccleston et al., 2011, p. xxiv)

The main goal of an EnMS is to continually improve energy performance. Energy performance is defined as the measurable results related to energy efficiency, energy use and energy consumption. It does not only involve the technical but also an administrative and management approach in which top management and all the organization's employees are tasked to make a contribution and joint efforts. The common definitions of the energy related terms are stated in ISO 50001, Chapter 3 as following

Energy efficiency - the relationship between an output of performance and an input of energy

Energy use - application of energy, e.g.: lighting, heating, cooling, transportation, data storage; also referred to as „energy end-use "

Energy consumption - is the quantity of energy applied and is displayed in energy unit like kwh, Joule or similar

SEUs – Significant Energy Use - energy use representing a considerable energy consumption and/or offering substantial potential for energy performance improvement

EnPI – Energy Performance Indicator - measure of energy performance, as defined by the organization (ISO 50001, 2018, p. 14)

2.3 Energy policy definition

The EnMS process is introduced with the formulation of an energy policy. According to Howell, an energy policy is a statement of an organization's policy for managing energy. It is comparable to a vision statement for energy. It should be applicable, actionable, future oriented, easy to understand, compelling, and consistent with policies of other management systems in the organization. (Howell, 2014, p. 21)

Definition of EP stated by Eccleston et al. is:

> "The energy policy commits the organization to achieving broadly stated operational and performance goals and objectives for its energy management system (EnMS) and defines the means for doing so." (Eccleston et al., 2011, p. 29)

The ISO standard (Chapter 5.2.) requires that top management shall ensure that the energy policy meets the following eight criteria:

(1) Policy appropriate to energy use - Policy should be appropriate to the nature, scale, and impact on the organization's energy use. Policy needs to make sense in relation to the company and its strategic direction.

(2) Commitment to improvement - The energy policy contains a promise to continuous enhancement in energy performance.

(3) Availability of information and resources - The energy policy contains a promise to ensuring the accessibility of information and resources essential to achieve the stated objectives and targets.

(4) Complying with requirements - It must include an obligation to meet legal and other requirements.

(5) Framework - The energy policy offers a system for setting and revising energy objectives and targets.

(6) Policy supports energy efficiency - The energy policy assists the buying of energy efficient products and services.

(7) Communication of the policy - The energy policy is written and communicated within the organization.

(8) Policy updating - The energy policy is repeatedly revised and updated according to the needs of the organization. (ISO 50001, 2018, p. 19)

As stated by Brugger-Gebhardt, Jungblut, energy policy may be visionary. Not seldom formulations will be found within an energy policy which we will consider unachievable

(Brugger-Gebhardt, Jungblut, 2019, S. 50). The energy policy must show the direction, a message for all stakeholders that the company is striving for a high energy standard.

Usually an energy policy is worked out in several workshops with the management team and experts. The policy should be formulated so that it is understood by all stakeholders. Especially the company's employees have to support the EP.

The company energy policy must grow and develop with the company. The energy policy should therefore be adapted to changing conditions. Management can do this in the management assessment and regularly ask the question: Does energy policy still suit us?

2.4 Energy efficiency in public transport

Development of PT in cities dates back to industrial revolution and growth of the cities in 19th century. Invention of electrical street cars brought rapid expansion of the urban transportation systems at the beginning of the 20th century around the world (Vuchic, 2007, S. 5). White makes the point that today the benefits of PT especially in urban areas are recognized, and energy and environmental issues favor a wider role for public transport in the future (White, 2009).

Urban mass transit systems are regarded as an ideal solution to reduce climate impact of mobility in the city due to great capacity and excellent environmental performance. However in the competitive context other transportation modes, especially the individual automotive sector, are developing their performance and climate impact fast, it is important the urban transport system reduce its energy use and costs while keeping the high service, comfort and reliability (A.González-Gil, 2014).

According to Eschweiler, another motivation for active energy policy is to strengthen the "brand" of public transport in the core perception as a climate friendly transport service provider and partner. The passengers expect to see environmental efforts and development in public transport. Car usage is still the main competitor with other modes (car sharing, scooters, bikes, taxis, robotaxis) developing. Municipalities which have to decide on the allocation of funds for public transport, want to see progress. Furthermore, increases in efficiency and in use of renewable energies are the core elements of the energy transition. However, the todays energy demand cannot be covered with renewable energies at today's level. Therefore, energy demand has to be reduced and public transport must contribute to this goal (Eschweiler, 2014).

2.4.1 Characteristic of energy flow in PT and energy saving measures

PT companies in large cities with transport systems such as the metro, trams and buses there show common characteristic for energy consumption and use. The local energy consumption

is subject to local demographic and economic structures, density and design of the urban structures. (Kaza, 2020, p. 2)

The main purpose of the transport service is to move passengers from one place to another with the objective to offer fast, reliable and comfortable travel (ELIPTIC, 2018). In every daytime and every season of the year. In order to offer this service and accomplish it successfully there is a complexity of tasks to manage.

The longevity of investments in infrastructure and vehicle means that investment decisions are taken years before the operation of the transport service starts.

The energy source is defined by the vehicles in operation and by the installed equipment in the stations and related infrastructure. The common energy source is electricity, fuels and steam, natural gas. Metros and trams are vehicles powered by electricity. Buses use in majority fuels like diesel, CNG and the next generation of buses will use electricity and hydrogen. Buildings like stations, depots and offices are using electricity, natural gas or district heating.

The use of energy can be divided by the different players into four main clusters:

- vehicles,
- infrastructure,
- buildings and
- operation.

It means there are also many people involved with different expertise and tasks. The engineers are mostly interested in a safe and modern technical equipment and the operators wish to satisfy the passengers with fast service.

Vehicles - Trains

Metro and tram vehicles today are designed for a lifespan of around 40 years. In many cases, rail vehicles are special constructions that can only be used in the vehicle customer's network. In combination with the comparatively small numbers in which the vehicles are manufactured, both factors lead to high procurement costs, which is why it would be uneconomical to replace the vehicles with more modern vehicles long before the actual end of life. Instead, rail vehicles are relatively well suited for carrying out extensive modernization measures.

The use of energy in a train can be divided into propulsion, HVAC, compressors, doors, lighting, controls and in-vehicle transmission losses. An example of an energy flow is shown in the Figure 2 Typical energy flow in a metro system. Similar to household applications the HVAC can be reduced by temperature settings and the insulations of walls, doors, windows, floor and ceiling of the vehicles. These measures are primary designed to new vehicles, but some retrofit is also possible. The use of heating pumps may lead to energy savings. This

equipment can be used as air-conditioning during the summer. The recovery of heat produced by the traction equipment could be reused for heating purposes, although the dispersion of the heat sources is an obstacle for the implementation of these new concepts. Equipment such as the CO2 concentration sensors in the ventilation system can significantly influence the amount of fresh air that need to be heated or cooled and adjust the amount of air to optimal level and thus increase efficiency.

Weight also affects energy consumption in railways (Eschweiler, 2014) . Lighter vehicles need less kinetic energy and therefore have lesser traction consumption. Examples are using lightweight materials such as composites in bodyshell, windows, passenger interior, doors, floors.

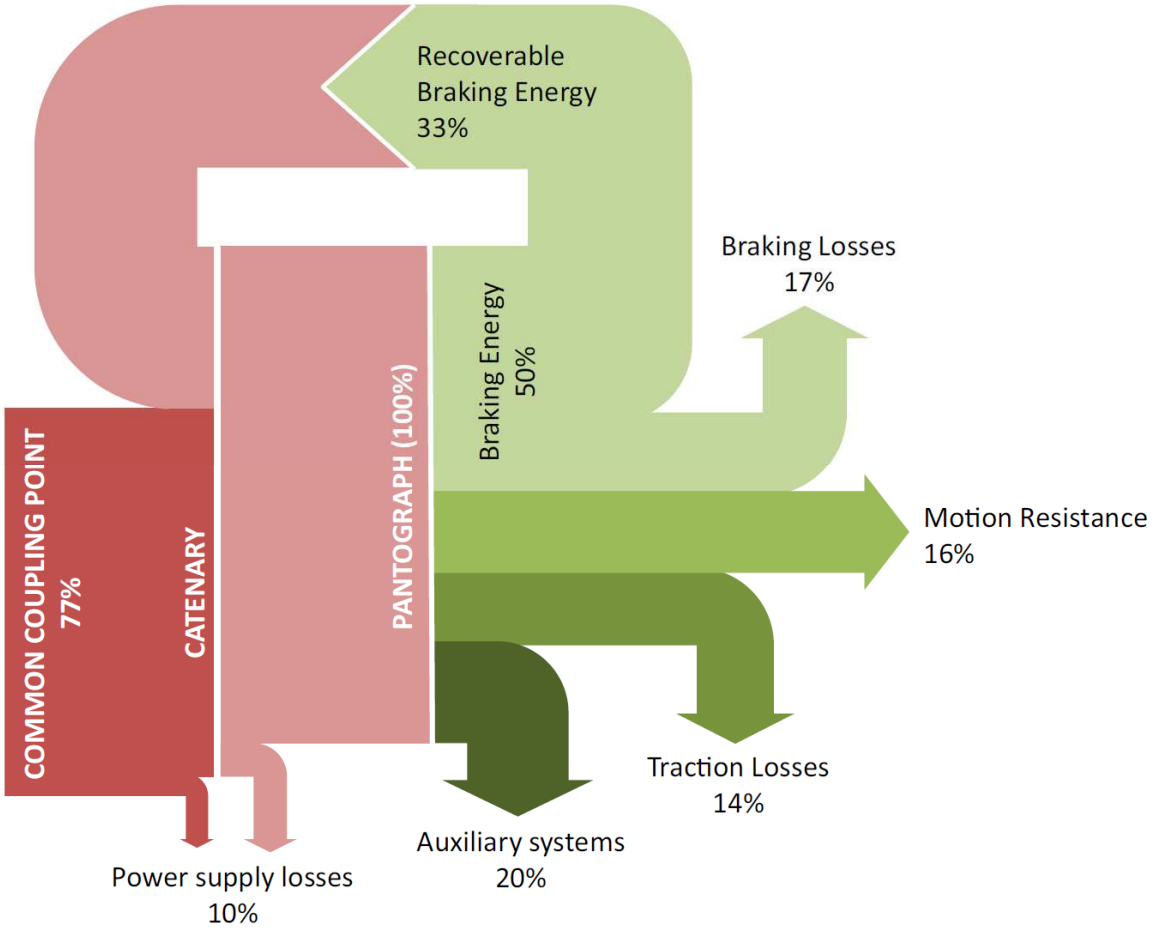

Figure 2 Typical energy flow in a metro system. (González-Gil, Palacin, Batty, 2015)

Braking energy recovery

All modern metro train have the ability to recover the kinetic energy as electrical energy when breaking the train. Small part of the energy can be used directly to power auxiliaries in vehicles, but the significant amount of energy is sent back into the rail network. This can only happen

as long as the voltage fluctuates above the open circuit voltage and below the brake voltage of the vehicle. This results in a voltage gap, which can be used for regenerative braking. The brake energy transfer additionally depends on parameters like intervals, distances between the stations and topology. If there is no moving vehicle in the area of the regenerative vehicle, this energy is converted into heat in the braking resistors on the train and is therefore lost (Ticket to Kyoto, 2014).

There are several approaches to reduce the energy loss in the metro system (A.González-Gil, 2014). Optimizing the service timetables to increase the energy transfer between vehicles. This can be seen as an organizational planning task supported by control systems. A higher grade of automation will support this measure and driverless metros operations will result in more improvement.

Using trackside or on-board energy storage systems to store the braking energy for a short time period and re-use is for the next accelerating train is a further option. A trackside storage takes the energy from a braking train close by and release it with depending on demand of an accelerating train. The system can be used also for voltage stabilization and peak power shaving. On-board storage saves the energy temporary for the next acceleration phases. The large space demand and weight of this system in the vehicle is an obstacle for the practical installation in existing vehicles. The available technologies include batteries, double layer capacitors and fly wheel.

Reversible substations include invertors enabling bidirectional flow to send the regenerated energy back to the AC network to power the equipment like lighting, elevators, etc. in the metro stations or connected systems. The AC lines are continually having demand for power, so the capacity for energy recover is large. The longevity of invertors is longer comparing to storage systems. Grid infrastructure that already exists in these systems can be used for this additional purpose.

Electrical supply systems

The companies operating rail systems have large electrical supply systems. Starting with connection to high voltage public grid and continuing with distribution networks and substation to convert the AC to DC power. The nominal power of the rail systems is usually 600, 750,1200V or 1500V DC. The direct current network feeds a power rail or an overhead line. In the normal operation, all sections of the line and both operating tracks are connected to each other. In the longitudinal direction there is a connection via the respective busbar of the substations. The supply systems are often interconnected for more metro and tram lines.

Optimal control of the traction facilities considering the operating settings can as well contribute to efficiency. The large supply networks operate many transformations, losses in grid are an

issue. For instance, to switch off some transformers during off-peak time can reduce losses (A.González-Gil, 2014). Good knowledge about the electrical network is a precondition to these measures. The setting in the DC rail network is responsible for the efficiency of the use of braking energy. The setting needs to be optimized together with vehicle technical specification.

Stations - Depots - Workshops

Infrastructure is constructed and installed to enable and support the transport service. Metro stations are very frequented places with numerous technical equipment. Main consumers of energy are HVAC Systems, lighting, groundwater pumps, escalators and elevators. Also, additional services like shops make a difference for the energy consumption.

Proper lighting provides the basis of comfortable and safe travel especially in underground systems. The operating time of the lighting can be up to 20h or 24h per day and lighting is therefore a significant energy consumer. The use of new technologies such as fluorescent and LED lamps while replacing existing system can lead to substantial savings. Automatic adjustment of lighting intensity to daylight and passenger flow can help to reduce the operating time. The longevity of the lighting equipment is also an issue for metro systems because the replacement often has to be done during the night hours and is therefore costly.

The heating and cooling load is especially high in technical rooms and workshops. Initial investment in smart design and renewable energy sources like geothermal energy, maximal heat recovery with heating pumps and solar energy increases the energy production on site and saves energy costs during operation time. The local generation of energy reduces the demand from public grid. Installation of modern control systems i.e. for ventilation and a regularly evaluation of its settings can be very significant contribution to saving energy.

Escalators located in station are operating during the whole service time. The modern systems have a voltage frequency drives that allows low speed when there is no demand, smooth start and stop. Existing escalators can be refit with more efficient motors, which has the potential to be a significant saving.

The metro trains are accommodated in depots and parking facilities during the idle period. If it is useful for the start of the operation in the morning, it can also be parked on the track. Due to maintenance and cleaning activities the trains partly stay switched on during these hours. The implementation of automatic control systems for comfort functions of the trains may reduce the energy consumption in park mode. The trains enter and leave the depot a few times a day and automatic fast opening and closing of the large doors has a positive impact of heating and cooling demand.

The alignment and the topographical conditions of the track systems are essential for energy performance. The location of the station is important when it comes to minimizing the energy

consumption by using the gravitational energy from acceleration and braking. (Vuchic, 2007, S. 136)

To ensure the functionality of a point switches at low temperatures, it must be equipped with heating to prevent icing. For this purpose, heating elements are installed in every switching point exposed to the outside weather condition. The annual full load hours of the heating system depend heavily on the weather. Modern point heaters are controlled by temperature and humidity sensors and these saves energy and helps to avoid unnecessary heating. (Ticket to Kyoto, 2014)

Large parts of metro systems are under the ground and tunnels are a large part of the infrastructure. Air ventilation consumes significant power. To maximize natural ventilation is a main factor as it allows the evacuation of heat in a natural way. (González-Gil, Palacin, Batty, 2015)

Safety systems and eco-driving techniques

The advantages of automatic train operation are that inaccuracies of the driver, as they occur in manual operation, are excluded. The influence of manual procedures can be minimized by the grade of automation (GOA) and real time control of the trains. Energy-optimized driving is characterized by high acceleration, a low switch-off speed, a long coasting time, a high braking deceleration. These steps can be managed by a safety system by controlling the driving and braking of the vehicle. Despite the short distances between the stations, significant reductions in energy consumption are possible by coasting. The stopping time in the station for passengers to get on and off the vehicle makes a difference for energy consumption too. If the train is running late, it will have to run on the maximal velocity.

Vehicles - Buses

Buses are manufactured in much larger quantities compared to trains, because in contrast to rail transport there are no regional infrastructural differences and the individualization of the vehicles is usually limited to design issues. On the one hand, this results in reasonable prices for new vehicles and, on the other hand, a considerable market for the resale of used vehicles. The replacement of a bus fleet is therefore possible and necessary within a much shorter period of time, even with a fleet size of several hundred vehicles, which means that technical developments can happen relatively quickly. At the same time, there are very few incentives to make changes to increase energy efficiency in existing vehicles.

The energy consumption is influenced mainly by the weight, engine and gear optimization, HVAC, lighting, opening doors, tire pressure. All buses are driven manually, so driving behavior is an important issue for energy consumption. Therefore, regularly eco-driving trainings for

drivers are useful and a common measure in the driver's education. Eco-driving means smarter and more fuel-efficient driving the comfortable feeling for the passengers. Supporting systems on the bus show actual information about the energy consumption support and motivate the drivers for eco-driving. Telematic systems provide information about every bus and enable a detailed monitoring for the company. (Ticket to Kyoto, 2014) Using dedicated bus lines and traffic lights control is not only beneficial for the traveling speed but also for energy consumption.

Diesel buses with EURO 6 engines are currently widely used (ELIPTIC, 2018). The intention to reduce the climate impact of the bus operation and improve energy efficiency leads to development of alternative propulsion systems. Next to hybrid buses electrical buses are the most promising alternatives. The main challenges in electrical buses are the driving range and the reliability of service in addition to low a standardization and unmatured manufacturer market. Due to limited battery capacity the driving range and the heating/cooling demand are in competition to each other. The ambitious goal of clean vehicle with no diesel heating/cooling comes with restriction on the kilometer range, especially in extreme weather condition. The requirement for reliable and efficient service needs to be fulfilled with every technology.

Additionally, the bus operators have to decide on the charging technology for their fleet of electrical buses and the operational constraints. Charging with bottom up or down pantograph is one of the options followed by plug-in cable. There can be charging infrastructure solely in bus depots, requiring the return of the bus to the depot according to driving range. Another approach is to install charging points along the bus lines, mostly in final stops to recharge the electrical bus during the turn-over time. This solution results in new challenges for the bus operator that are similar to the ones a tram network operator faces.

The installation of a connection to public electrical grid in the city with all the space, cost and availability dilemma can be problematic. The procurement of electrical buses is not a single vehicle choice liked it used to be with diesel bus, but it is a complex decision about line planning, charging and battery usage. The choice of the technology solution is subject to the local situation and operational settings, which each operator needs to analyze.

The high-power demand of electrical buses can be a hurdle and a huge cost factor for the realization of a project. Therefore, the integration with existing electrical supply network need to be examined in the first step to get a clear understanding of capacities and unused potential. The so-called smart charging is a key to an optimized use of the infrastructure. Another beneficial approach is the integration of renewable energy sources for charging the buses, like the installation of photovoltaic in bus depots (ELIPTIC, 2018).

A systematic overview of relations among the discussed characteristics and factors influencing the energy consumption is given in the following figure.

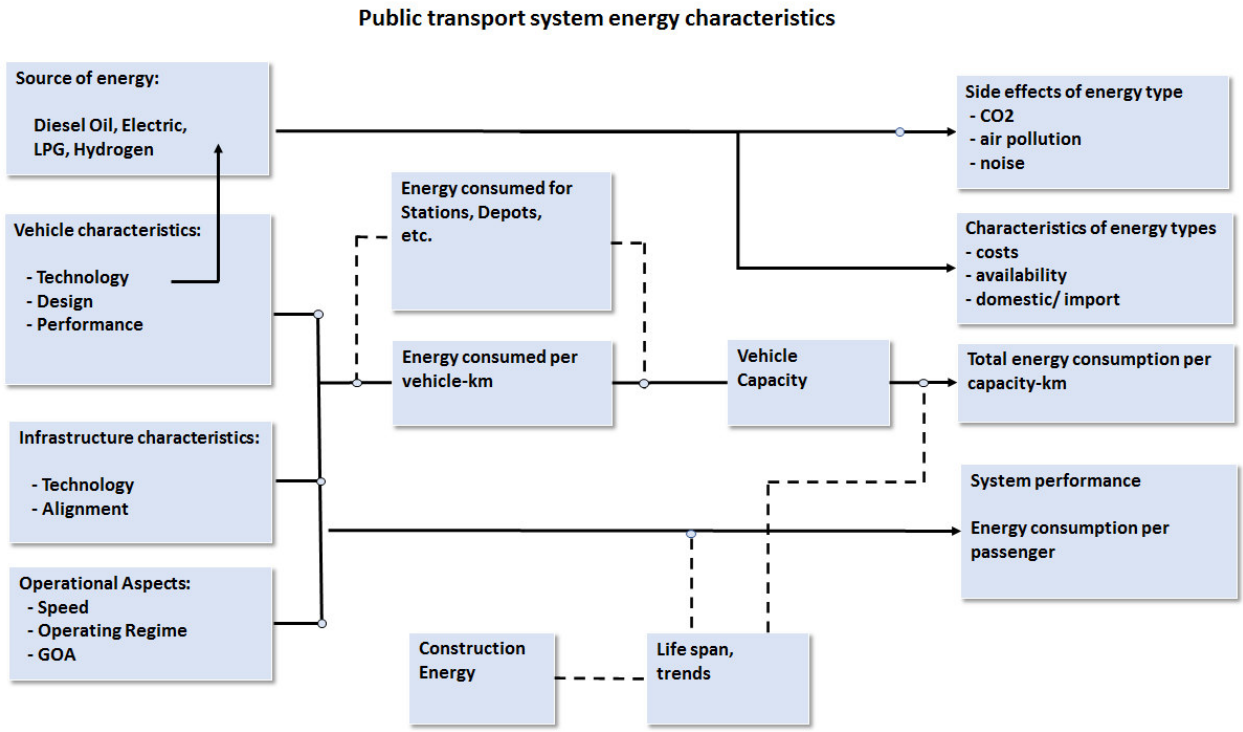

Figure 3 Public transport system energy characteristics, adopted from (Vuchic, 2007, S. 156)

2.4.2 Energy monitoring and KPIs

To practice a well-functioning and consistent energy management it is essential to have a deep understand of the energy flow and significant energy use. Therefore, metering of energy is a vital part of energy management and key to success. (Ticket to Kyoto, 2014)

Geilhausen et al. defines monitoring as the evaluation of the energy data with constant and regular observation. The energy monitoring represents the control task of EnMS. A control of the parameters with the ability to warn if deviations occur. The aim of the monitoring is to avoid unnecessary energy consumption and to monitor the energy aspects in operation (Geilhausen et al., 2015, p 310).

Partly energy monitoring can use data from the SCADA systems or install dedicated meters for energy monitoring. The main target for the collected data is that they are showing the significant parts of the consumption and the data collection is done remotely, with no manual efforts. Interface to a data system to store and analyze data should improve with the growth of the energy management system.

Portable devices can also be very useful for temporary measurements after tests or pilot projects. Data can be also used to check the correct energy billing (González-Gil, Palacin, Batty, 2015).

The integration of energy storages and invertors as well es renewable energy generation in the public transport system will result in the need for detailed management of energy flows within the system. Growing integration between metros, trams and electrical buses will also increase the necessity of close monitoring and control of energy consumption with detailed information on every use. The data provided by the public grid operator is used for billing the energy but will not provide enough information about the energy consumption on site. This means that the number of measurements and data will increase and the systems for collection of data and analysis need to be robust.

Energy metering in connection to Energy monitoring and KPIs

In general, energy performance indicators represent the quantitative assessment of energy-related performance. The starting point for the definition of energy indicators is to be clear about the purpose of intended use of the figures and the reference values. The actuality of the input data and their availability has to be taken into account. (Geilhausen et al., 2015, p. 305)

The KPIs can follow different targets and all together they need to service the main goals defined in the energy policy in order to be able to follow the development and achievement of goals.

When designing the energy consumption related KPIs for PT the complexity and interdependences between the subsystems (described in 2.4) need to be considered. The goal of these selected indicators is to enable a multilevel analysis of the actual energy performance of the system. Furthermore, the indicators should give an overall picture and support the valuation of potential energy saving strategies. Additionally, the figures should provide a mechanism to monitor the progress and results of implemented energy efficiency measures (González-Gil, Palacin, Batty, 2015).

The suggestion of top ten KPIs for urban rail according to the results of OSIRIS (Optimal Strategy to Innovate and Reduce energy consumption In urban rail Systems) project is following (González-Gil, Palacin, Batty, 2015):

KPI01 – Specific CO2 emissions

This indicator mirrors the yearly amount of CO2 equivalent emissions (CO2e) associated with the energy consumption of the whole system per unit of transportation. It is measured in kg CO2e per passenger-km and can be used to compare the environmental impact of different urban rail systems between themselves or against other transport modes. Its control requires

knowledge of the total energy consumption by type of source in the system (e.g. electricity, gas, renewable energies, etc.) and their respective CO2 conversion factors.

KPI02 – Specific energy consumption

This figure measures the global efficiency of the system. The base for the calculation is the total yearly energy consumption per passenger-km, which contains both electrical and thermal energy. Its consumption comprises not only energy taken out from the public network, but also all electricity generated within the system, either from renewable or from fossil sources. In case the part of the regenerated braking energy is sent back to the public grid, it must be accounted as outflow.

KPI03 – Share of renewable energy

This indicator states to the proportion of the system's yearly energy consumption that is supplied by renewable energy sources generated within the system itself. It shows the effort made by the system to reduce its environmental impact and therefore this figure could be used to strengthen the public image of the company.

KPI04 – Waste heat recovery

The recovery of waste heat could help reduce the total energy consumption in the system. Targeting to quantify the energy savings generated by such measures, KPI04 is calculated as the percentage of the total energy usage that is recovered and reused as waste heat within the system. The examples of waste heat can be at vehicle level from braking resistors or other traction equipment. In the infrastructure the heating of underground stations and staff rooms can use warm air in tunnels.

KPI05 – Traction power supply efficiency

This indicator evaluates the efficiency of the traction power supply system, which includes both the substations and the power distribution network. It is defined as the electricity consumption of all trains in the system while they are in service over the total energy consumption for traction purposes measured at substation level.

KPI06 – In-service traction energy consumption

This KPI calculates the amount of energy specifically used for traction purposes in the system and unit of transportation (i.e. passenger kilometer), excluding the consumption of on-board auxiliary systems. It is intended to reflect the energy savings applied to the vehicle's traction system. If the indicator is used for comparison with fleets in different systems, the influence of i.e. track profile, stops frequency should be taken into account.

KPI07 – In-service auxiliaries' energy consumption

This KPI measures the annual energy consumption of all vehicles' auxiliaries in the system per passenger-km. Different energy efficiency measures focused on comfort functions in vehicles can be evaluated with this indicator. The climatic conditions may have a substantial influence on this figure.

KPI08 – Braking energy recovery

This indicator looks at the use of regenerative braking technologies. It is defined as the percentage of the yearly traction energy consumption that is recovered during braking of all trains in the system. This includes the electricity sent back to the traction power supply grid and the energy reused and stored within the vehicles themselves.

KPI09 – Energy consumption in depots

This indicator computes the total energy consumption in depots, including the energy used by parked trains and the thermal and electrical energy consumption of depot buildings. Denominator for this indicator is the passenger capacity of all the trains in the system. Climate conditions should be taken into account when comparing with other systems or periods.

KPI10 – Energy consumption in stations and infrastructure equipment

This figure expresses the energy consumption of all stations and infrastructure related facility in the system per km of network. Typically, it will also include the tunnel ventilation systems and both thermal and electrical energy consumptions in the stations.

These top KPIs can be supplemented by details from each subsystem. For examples the KPI for stations could provide further indicators about energy consumption for main influence like lighting, HVAC, tunnel ventilation and escalators.

For each project or an efficiency measure there can be realized a specific set of data and performance indicators on a temporary basis to follow the expected savings.

3 Research Methodology

After the theoretical framework about the definitions in energy management and overview about energy efficiency in public transport the next part of the thesis is more practical.

The core of the practical part of the thesis are several standard analysis and interviews with experts from PT companies in Europe. The analytical methodology is chosen to gather more insight about different influences on energy related topics for a public transport company.

First, a stakeholder analysis is carried out to find out which actors and parties are interested in this topic, and their stake is described and analyzed. In order to better understand the main external influencing factors, a macro-economic PESTEL analysis is carried out. The main drivers in the areas of politics, economy, social affairs, technology, environment and law are listed and validated.

The findings of the previous parts will serve as inputs for the preparation of the interviews with experts. A questionnaire for semi-structured interviews the senior experts will be prepared in advance. The questions will be prepared and sent to the participants in advanced. The interviews will be held over the phone or answered by e-mail. The interviews will be recorded and transcript according to the guideline for thesis. The findings will be summarized and analyzed with focus on best practice. An example of a multi-criteria analysis for energy related decisions will be presented.

Finally, all findings will be connected to a conclusion to answer the research questions in the best way from the theoretical and the practical part.

3.1 Preparation for the interview

The interviews with experts in public transport are also a part of this thesis. All interviewees work as managers for public transport companies in Europe and are involved in energy management at company level. The interviewees were chosen according to their long-term expertise in this field and enthusiasm for the clean energy future of public transport.

The questionnaire is divided into four thematic pillars, that focus on details related to energy policy, energy management, renewable energy and open additional comment. The questionnaire will be distributed in advance as a guide for the talk. The interviews will be conducted over the phone or e-mail. Following topics and open questions are part of the interview:

Pillar 1 Energy Policy

- Is there an energy policy in your company?
- How important is it? How is it communicated internally and externally? Are the stakeholders interested?

Pillar 2 Energy Management

- How is the energy management structured in the company? Who is involved?
- What does the team look like?
- How is the potential for improving energy efficiency determined?
- What criteria are used to measure energy efficiency measures?
- Which energy-relevant project has you been dealing with recently?
- What specific energy related project do you plan to implement in the near future?
- How does the monitoring of energy efficiency measures work?
- Which KPIs are reported periodically? Who is the report directed to?

Pillar 3 Renewable Energy

- Do you use renewable energies on site? Which sources are you already using? Are there any expansion plans?
- What electricity mix are you currently using? How do you get the energy?

Pillar 4 Discussion

- What else is important to you regarding this topic?

3.2 The PESTEL analysis - Methodology

A company is wrapped in several shells, whereas the outer shell is the macro-environment. The macro environment may seem far away from one's workplace but it is permanently exercising extraordinary forces on the industry, the market, the company, the business unit one works for. These forces are political, economic, social, technological, environmental and legal (Johnson, Scholes, Whittington, 2008, p. 54).

This macro-environment is changing and with these changes taking place it redefines the industry and is markets. As there is no standstill these forces permanently penetrate a company and its business units and one's workplace. These forces are driving elements for every company. One should know these forces.

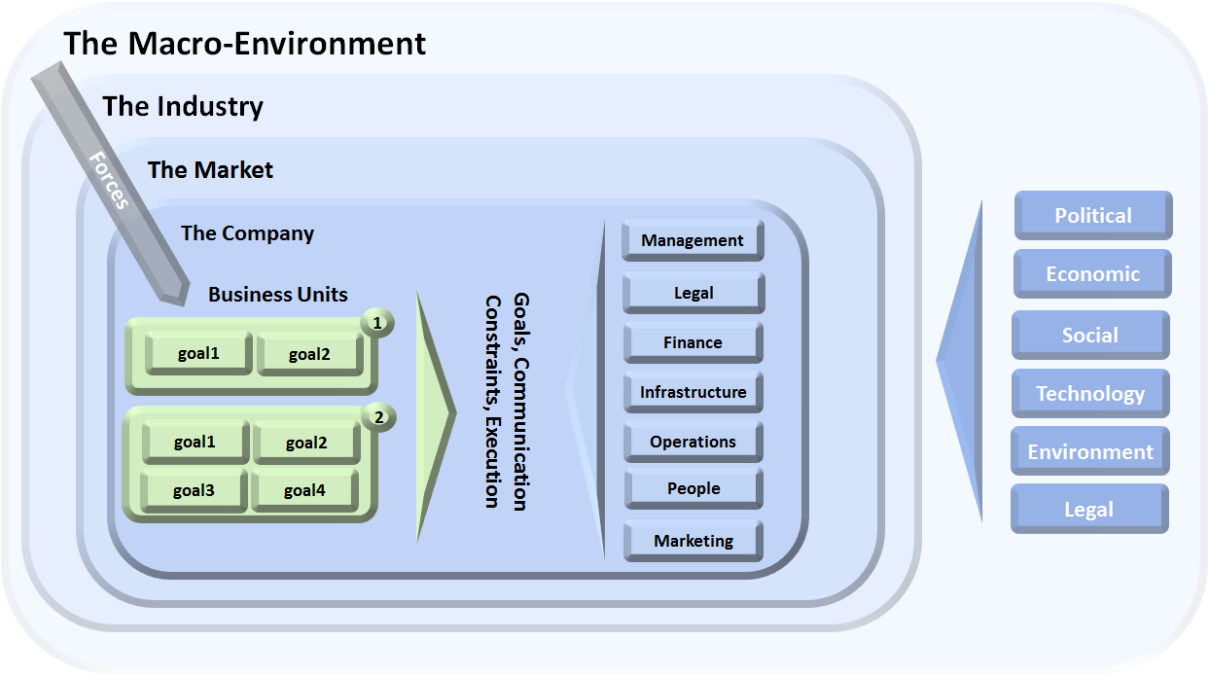

Figure 4 Environments

The macro-environment is the highest-level layer. The forces there have an impact on almost all organizational levels. The PESTEL framework is useful to understand how these macro elements now and, in the future, influence the organization. The PESTEL concept is useful in many cases and can be applied to different situations.

Structuring the most important factors in different areas helps to keep oversight and support a decision-making team to look from different perspectives at ventures and problems. This helicopter view does not show everything, but it is helpful not to get lost in details.

PESTEL offers an overview and support finding what are most important significant drivers. Scenarios can be built to explore key drivers in different ways to follow the macro-environment change. (Johnson, Scholes, Whittington, 2008, p. 55)

The PESTEL analysis became an important strategic analysis tool in which the effects of external factors on a company are assessed. Ideally, this environment analysis is carried out regularly in order to detect changes in the influencing factors. It identifies possible developments and trends that may influence the company and its strategies in the future and is therefore an important management tool in strategic management.

PESTEL may be applied for a venture, it may be applied for projects, for decision making situations within a company, for business units within a company.

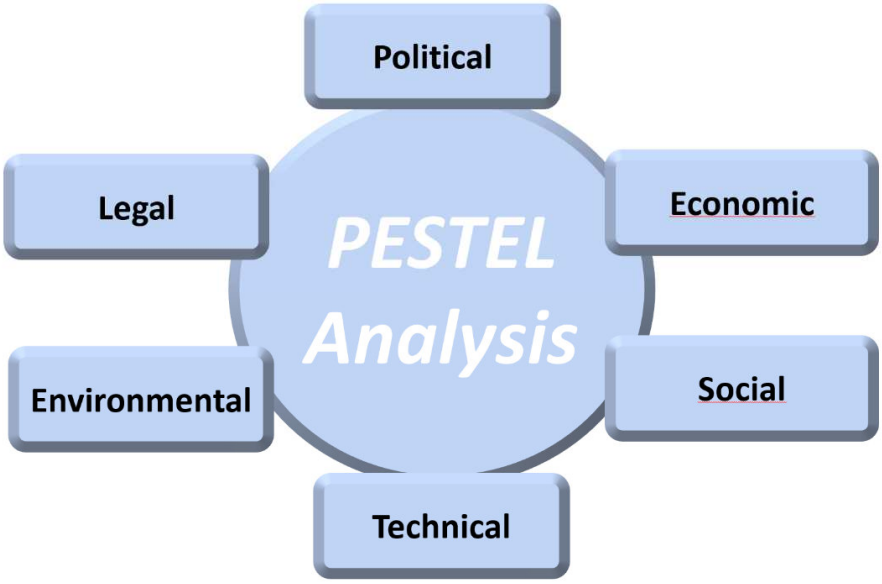

Figure 5 PESTEL Framework

The PESTEL framework categorizes macro environmental influences into six elements: political, economic, social, technological, environmental and legal. Factors can be identified within these areas and there are interdependencies between these areas.

A political decision to impose customs duties may intend to protect the industry but lead to less competition to higher prices and even inflation and create effects for a profit/loss statement.

Technology factors in the field of renewable energy development simultaneously influence economic factors by creating jobs, may influence environmental factors by reducing pollution. A change in GDP will influence sales, jobs, income, leisure behavior, energy consumption, energy prices. It therefore makes sense to categorize factors according to their influence or dependencies.

Analyzing these factors and their interdependencies will produce long lists. Not to get overwhelmed by details, it is necessary to reduce this list of factors focusing on the significant high-impact factors for success/failure/risk. Typical key factors will vary by industry or sector.

Here are some examples for PESTEL factors (FMW, 2013).

Political

When deciding for a location or choosing a market, political factors play a major role. Governments use this opportunity to pursue active economic policies. This affects authoritarian states and also democratic countries and national associations such as the European Union. On the one hand through local subsidies and subsidies, on the

other hand through punitive tariffs and import bans. These serve as an incentive to invest in the country or to enter into a joint venture.

Economic

In export-intensive countries and industries, economic factors such as GDP, inflation, exchange rates cost of labor and materials, energy are of enormous importance. A strong local currency means that price increases may be a competitive disadvantage. High economic growth and a rising level of education indicate a growing market and increased opportunities.

Social

These influencing factors are about determining which special social and cultural characteristics exist. This includes changing buying behavior and generally changing lifestyles.

Technological

The current core topic in terms of technological influencing factors is digitization and automation. The technological influencing factors of the PESTEL analysis can be related to the manufacture and the infrastructure, such as factors contributing to improved quality of products or cost savings.

Environmental

The environmental factors include, for example, environmental requirements that can have a strong impact on a company's investment plans. Noise, pollution or water-specific requirements can vary greatly from country to country.

Legal

The legal factor is a strong force as it defines the environment of industries Energy law is relevant to all companies within the energy market and consumers. The specific design of what is permissible and what is not differs from country to country.

PESTEL methodology can be successfully used in different fields. The result of the PESTEL analysis is often used to identify threats and weaknesses as input for a SWOT analysis. These tools are often used together as they complement each other.

A SWOT analysis may include information from a PESTEL analysis. Setting up a SWOT Analysis means categorizing factors into strength, weakness, opportunity, threat.

The procedure of the analysis can be summed up in following steps:

- Identify macro and microeconomic factors
- Understand the factors and the interdependencies of factors
- Know the power a factor may excerpt on the project or issue
- Categorize factors into positive or negative or into the SWOT categories

4 Practical part

4.1 Stakeholder Analyses

Stakeholder is any entity that has an interest (“stake”) in the organization (A.Schilling, 2020, S. 127). Typically, the first step is to identify all the parties affected by the company's behavior.

The company must determine which groups are interested in the company and have an impact on the company. It is also necessary to determine what requirements these interested parties have that affect their energy consumption and performance.

These people or groups have their own needs and expectations that differ from the stake of the company. However, since the company works with these parties, the expectations of different groups may conflict, and some groups may have the same needs.

The various requirements must be collected and analyzed to serve as input for the definition of the company's energy policy. The following stakeholder analysis shows the list of stakeholders that are relevant for a public transport company in the energy sector. Before setting up an EnMS, it is advisable to consider the interests, influence, contribution and support of stakeholders.

4.1.1 External stakeholders

Passengers

Passengers appreciate a fast, comfortable and reliable service. They wish for an affordable transportation service and a well-connected and growing transportation network. If they choose to leave their car at home, they are proud to use PT and support the environmental issue and CO2 reduction. They want to receive information about sustainable activities and improving energy performance of the company and the transport system they use. Some of them wish to be involved in decision making process.

Owner/City Council

Providing PT is what people expect in a modern city. The city government is directly involved in public transport and has to subsidize expansions and lead the further development. Good public transport is a political issue. Mismanagement may determine the fate of a city government, and PT is so closely linked to the city's economic functioning. Public transport is a figurehead for a city. Environmental expectations, low emissions and innovation are further expectations of the city. The smart city strategies are based on energy issues and public transport.

Government, Authorities

The government is interested in achieving climate goals and fulfilling its commitment to reduce CO2. Awareness that PT makes a relevant contribution to achieving these goals is important. In this sense, the government should support the PT through subsidies and laws. Expansion of the PT system is the common goal to use the most efficient means of transport and to make use of all possible improvements. An efficient transport system helps to attract investments, develop business and improve the lives of citizens.

Security of the energy supply is a concern of the authorities and the regulation for back-up systems are inputs for the design of the energy systems in PT, i.e. installation of diesel engines and uninterrupted power supply unit.

Suppliers

PT's infrastructure is very complex and includes a large number of external suppliers. Innovation takes place in a form of partnership with these suppliers. The energy supply side is important, and it is essential to work closely with an innovative supplier who knows the energy market and offers opportunities for optimizations. The decision for a specific energy mix and fuels composition is a part of the energy policy and a supplier may support these decision-making processes.

The procurement of the vehicles and infrastructure is one of the first steps to influence the energy consumption, so the supplier need to understand the priorities and goals. With a long-term infrastructure, the relationship with the supplies is also stretched and trustworthy. The ideas for refurbishment and operational changes often need bilateral cooperation. Maintenance agreements can also affect the energy efficiency.

Associations

PT has a long tradition in building associations, like UITP (International Association of Public Transport), to enhance the exchange of experience and information and to bring all players in public transport together. The aim is also to provide benchmarking and information on news trends for technologies and services. International and national energy agencies offer also valuable support in energy planning and development. The chamber of commerce and similar associations cooperate with law making authorities and support PT companies through lobbying activities. ISO association organize the development of standards and common terms also in energy field.

Research partners and universities

Collaborating in research projects with partners can offer a few advantages such as the ability to learn and the transfer of knowledge. Some technical solutions have to be developed according to the special requirements of public transport such as durability and reliability. It can also be beneficial to bring in new ideas from outside the public transport industry. Projects related to digitization and data science can help identify and monitor the infrastructure and respond in time to reduce energy loss.

Neighbors

People living near PT want the PT infrastructure to look nice and feel a sense of modernity in its environment. They appreciate the proximity to the nearest tram or bus stop, but do not want to be exposed to noise or emissions. When refurbishments or new installations take place, the neighbors want to be informed and be part of a discussion process because the effects, which can last for months or years, can have a reasonable impact on the neighborhood's quality of life. In particular, the installation of photovoltaic modules and wind turbines are affecting the immediate environment.

The graphical presentation in Figure 6 shows the different level of interest and power in the energy related issue of public transport. The involvement reaches from information to partnership.

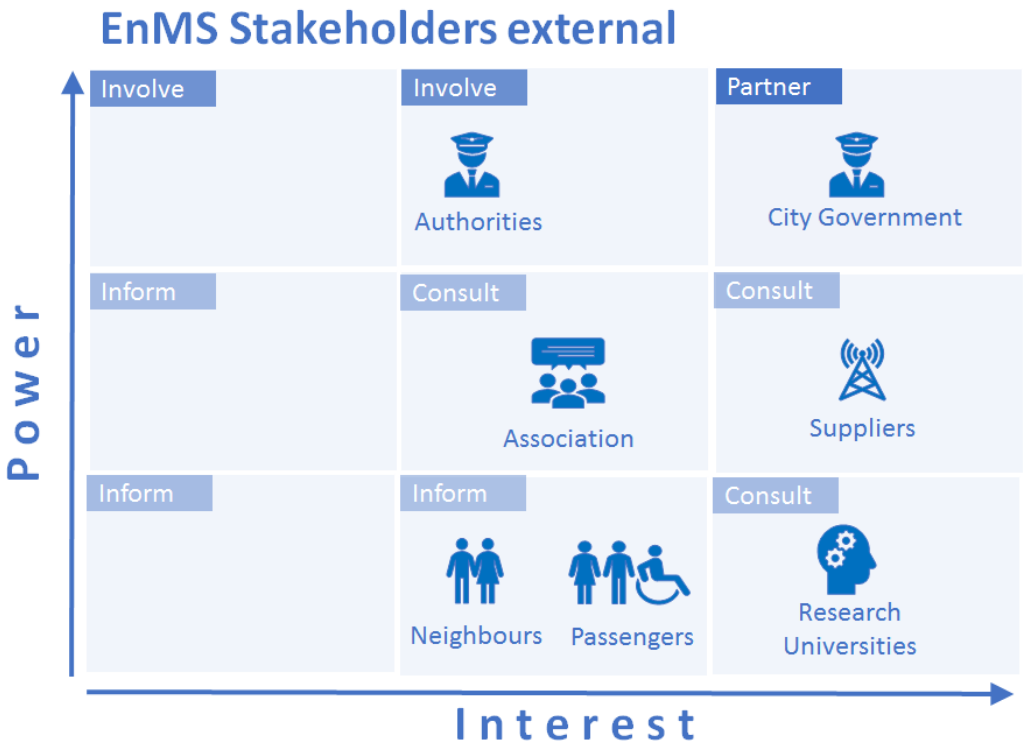

Figure 6 Stakeholder Analysis

4.1.2 Internal Stakeholders

As stated in the Chapter 2, the energy flow in public transport is very complex issue with many dependencies. It means there are numerous parties to be involved in the energy management process.

The **management**, as the main enabler of change and needs to commit to the goal of energy saving and decarbonization. Management is the one to control and communicate the progress openly. Good KPIs and benchmarking is helpful for decision making.

The **commercial department** has on the one hand the strategic view to cover the operational costs for the future and therefore increasing energy performance means saving cost. On the other hand, the necessary investments need to be financed. So, the challenge is to provide robust analysis and scenarios for the future demand in energy and its budgeting and to promote the understanding of energy related issues in the commercial department.

The **legal department** shall support the EnMS by monitoring the development of energy related legal issues very closely and by getting involved in lobbying activities and by the network of associations and chambers. These activities will enable the company to react fast and in time to changes.

The **marketing or communication department** has the direct connection to the customers, in this case the passengers. The positive image of the company is linked to its clean energy commitment (Winston, Favaloro, Healy, 2017) . When there is an incident affecting the passenger service, such as in the case of serious incidents in the energy distribution, good communication is key not to lose the confidence of passengers. On the other hand, providing regular information on energy policies, or about the projects in course related to improve energy efficiency will increase the customers knowledge of the company and about its commitment to sustainability and the environment. That improves the image of the company and customer loyalty will form a band with the passenger.

In the **vehicle department** the long life of the assets contradicts the focus on purchase of new vehicles and refurbishment of existing ones. Following industrial standards facilitate effectiveness of maintenance costs. The reliability in everyday service is essential. Changes in the equipment of the vehicles, even small are mostly the ones that are costly in the installation but durable in the savings and do not require continuous training or awareness.

The **infrastructure department** ensures the correct state of maintenance of the facilities to avoid energy loss. Renewing obsolete equipment with equivalents that take into account the energy factor will also provide improvements in energy efficiency. In the renewal of auxiliary elements for maintenance, such as certain machinery or tools, energy efficiency must also be introduced as a requirement in tenders. The organization and teams working in workshops can

also optimize energy consumption for the most relevant parts. The safe and reliable operation of the infrastructure i.e. electrical supply network is the main focus. Considering energy efficiency in everyday operation is something that needs to be reminded regularly and evaluated permanently with data.

The operation department aims to provide fast, reliable and comfortable service for the passengers. The pressure on fast service is not beneficial to energy consumption. So, the balance needs to be found, like using different speed in different time of the day. The training for the drivers and service staff in the stations are a strong force to improve the energy efficiency (Ticket to Kyoto, 2014)

Staff participation and awareness are an important part of an energy and carbon saving activities. **Employees** in general prefer to make progress in a meaningful work (Amabile, Kramer, May 2011) and wish to have a positive impact on the environment. Therefore, the involvement in EnMS can be a nourisher and have positive employee brand image.

4.2 Macro- economic Analyses (PESTEL)

Analysis of external and internal factors

To generate a reasonable list of factors for the PESTEL analysis it is recommended to bring a team of experts together and discuss energy related topics. The discussion could start with reaching a common understanding of the goals of an EnMS within the company:

- save energy,
- increase energy efficiency,
- reduce CO2 and
- reduce energy costs.

The next step is to find and evaluate the important factors that affect energy costs, energy efficiency, energy savings and CO2 savings. The following image shows more than 40 influencing factors linked to the goals at the top. The activity plan below is being developed as part of the EnMS.

Figure 7: PESTLE analysis for a PT company

After having identified the main criteria, it is helpful to chart the cause effect relationships. There are several options available. The following PowerPoint chart was made to identify forces that influence the energy price for a PT company. We can distinguish several forces from the economic, market, climate legal, regulatory side. The Figure 7: PESTLE analysis for a PT company is generally also valid for other energy consumers.

The PT company can optimize its procurement strategy to reduce market risks. It is also recommended to exercise influence on law makers in order to influence the definition of the regulatory cost elements which go on top of the energy commodity price. The energy laws may define green electricity flat rates, energy taxes, balance energy, subsidies and penalties. At the end of the day, the total energy price may consist of 40% for commodity, which is volatile on a daily basis and 60% of other elements like grid tariffs, renewable charges, taxes, levies, regulated by the state. (Geilhausen et al., 2015, S. 82)

GDP and the oil price are one of the most powerful sources to influence the market price for electricity. Factors may change and with their changes it may drive the energy price up or down. EnMS for a PT company as a large energy consumer shall be aware of these factors and the potential for change.

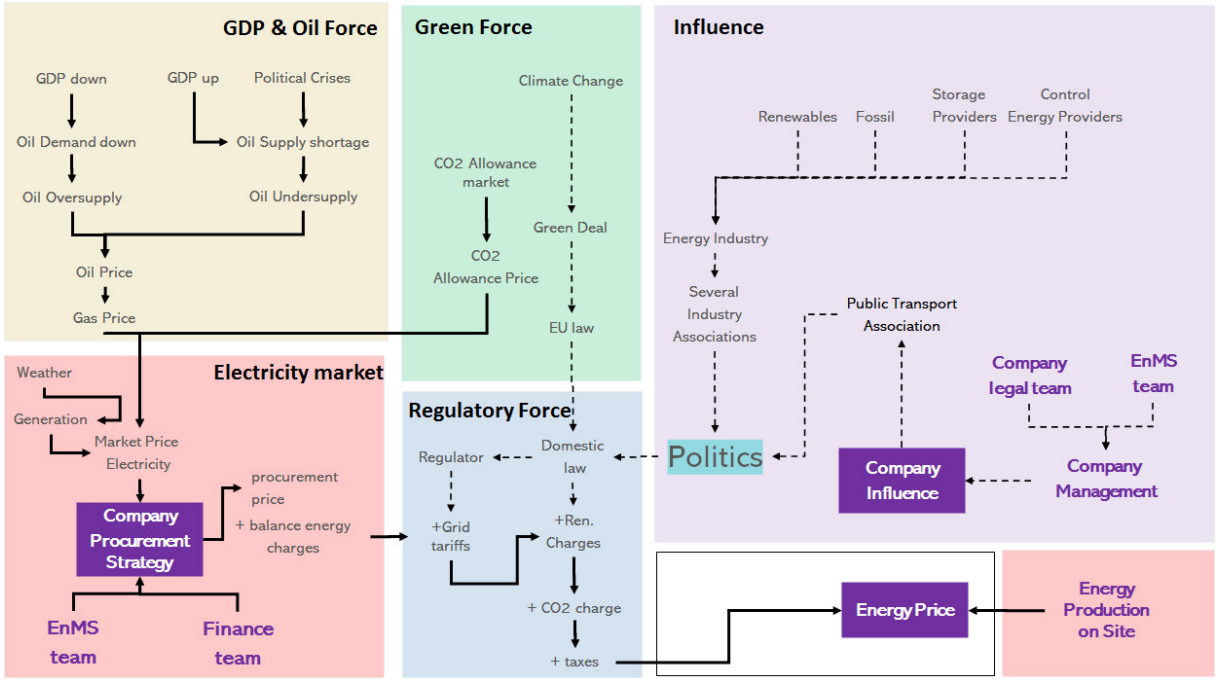

Figure 8: Influence on energy prices

When we look at the energy flow at a PT company there are some special features like many metering points and a geographical extension of the network. When regulatory changes are happening in terms of energy these features might be missed out. Legal departments at a PT company are challenged to monitor the legal side permanently, which means knowing what energy topics the are being discussed or planned by lawmakers on the European and national level. Figure 8 shows the described dependencies in a graphical way.

The following step is to concentrate on the most important strategic factors and analyze the selected ones in more detail. Here is a selection of PESTEL factors relevant for a PT company:

Clean Vehicle Directive - Political

The European Parliament and Council approved a new Clean Vehicles Directive in June 2019. The directive promotes clean mobility solutions in public procurement tenders of low- and zero-emission vehicles including purchase, lease, and rent contracts for light-duty vehicles, trucks and buses. The new directive defines "clean vehicles" as hydrogen, battery electric, natural gas, liquid biofuels, synthetic and paraffinic fuels, LPG. The directive does not specify the energy source for the production of hydrogen and electricity. The directive sets out mandatory minimum procurement targets in each Member State for 2025 and 2030 differentiated on the basis of GDP/capita and population density. Example for the bus quotas can be seen in Figure 9. On buses, 50% of the minimum target for the share of clean buses has to be fulfilled by procuring zero-emission buses – hydrogen and battery electric.

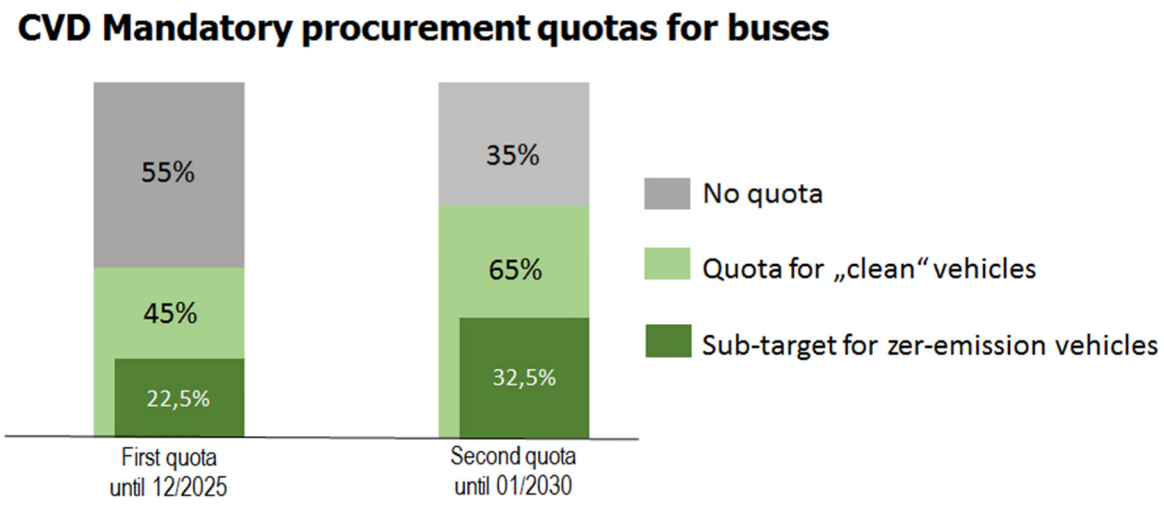

Figure 9: Example of procurement quotas for buses for the majority of the EU countries

According to the European Commission, the directive aims to stimulate the market for clean and efficient vehicles and to prompt developments and investments by the industry. Increased sales will help reduce costs through economies of scale and will result in progressive improvement in the energy and environmental performance of the whole vehicle fleet. The Directive needs to be transposed into national law by 2 August 2021. (European Commision, Clean Vehicle Directive, 2020)

EU Energy policy - Green Deal – Political

The Clean energy for all Europeans package is the central framework of the EU towards a carbon-neutral economy. EU, as an early mover on clean energy have set targets for 2030 backing the Paris climate agreement and fixing a long-term decarbonization strategy for 2050.

The package consists of eight legislative acts. The new rules contain the principle of “energy efficiency first”, and defines energy efficiency as a key to energy savings and the easiest way for reducing greenhouse gas emissions. The EU has therefore set binding targets of at least 32.5% energy efficiency by 2030, relative to a ‘business as usual’ scenario. The updated Directive on Energy Efficiency ((EU) 2018/844) has been in place since December 2018. Buildings are responsible for approximately 40% of energy consumption and 36% of CO2 emissions in the EU, making them the single largest energy consumer in Europe. The Energy Performance of Buildings Directive ((EU 2018/844) outlines measures for the building sector. Further the EU has set a target of 32% for renewable energy sources in the EU’s energy mix by 2030. The revised renewable energy directive 2018/2001/EU came into effect in December 2018. The electricity market design has now been established in the Directive on common rules for the internal market for electricity (EU) 2019/944, and the new regulation on the internal

market for electricity (EU) 2019/943, puts the consumer at the center of the clean energy transition and even actively allows consumers to participate as prosumers. This adoption of the Directive shall support investment in energy storage but also compensate for variable energy production. (EC, Clean Energy for all Europeans, 2019)

The package includes a governance system where each Member State is obliged to develop a present a 10-year national energy plan for 2021 to 2030. Theses national plans outline how the EU countries address: energy efficiency, renewables, greenhouse gas, emissions reductions, interconnections, research and innovation. Progress reports have to be delivered to the EU and are monitored by the EU. Additionally, Member States are required to submit by the start of 2020 national long-term strategies looking forward to 2050. (European Commission, National energy and climate plans , 2020). These plans differ from country to country, but all have a section regarding public transport.

In December 2019, the European Commission presented the European Green Deal, long-term climate neutrality strategy till 2050. In addition, economic growth should be independent of the use of resources. To achieve this, the EU's 2030 reduction target for greenhouse gas emissions is to be increased to 50-55% compared to 1990. The European Green Deal contains a total of fifty measures, which are divided into 9 areas. One of these areas is sustainable and intelligent mobility. A quarter of greenhouse gas emissions currently come from the transport sector, which is why it will be necessary to reduce transport-related emissions by 90% by 2050. The EK will adopt a strategy for sustainable and intelligent mobility in the second half of 2020. In cities in particular, traffic should become drastically less harmful to the environment. Important element is the strengthening of public transport and charging infrastructure for electrical vehicles. The European Commission will also continue to implement the strategic action plan for batteries so that a safe, cycle-oriented and sustainable value chain for batteries can be implemented, especially with regard to electric vehicles. (European Commission, The European Green Deal, 2019)

Global Oil - Political

Oil is an economic and a political factor. Political conflicts and GDP have an impact on the oil price. Political, military incidents may cause short-term rising oil prices, even the threat of such conflicts pushes the oil price. On the other hand, there is the financial deficit of oil producing states which need to be balanced by oil production. Balancing state budgets of oil exporting countries may be drivers for oversupply and drag oil prices down. The crude oil price is generally still one of the leading prices in the energy market, especially for fuels like diesel. Additionally, there are some other factors that may drive the oil price like oil storage in

refineries, ship capacity, ship freight rates. The oil price has implications on the gas price, thus electricity from gas production is indirectly but highly impacted by the oil price.

GDP - Economic

GDP influences the oil supply/demand curve and may drive the oil price and electricity price up and down accordingly. GDP indicates increases/decreases of production. The pandemic, that resulted from the spread of COVID-19 in 2020 showed this correlation quite dramatically. When GDP fell globally the oil price more than halved. The gas and electricity prices correspondingly fell all over Europe, because industry production was partly shut down. Due to the still existing international oil-gas price coupling, there is a further indirect dependency of the electricity price on the development of the oil price.

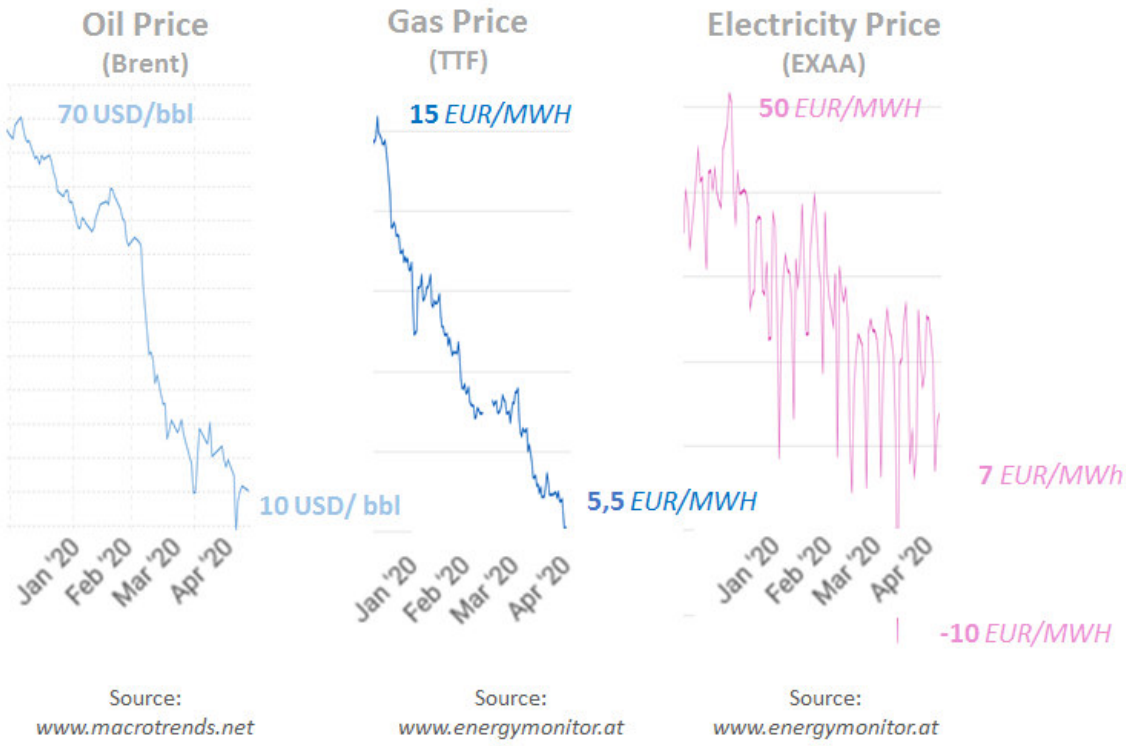

Figure 10: Market price curves 03.05.2020

Energy Market Price - Economic

Energy market prices are depending on generation plants and its resources like water, gas, sun, wind. Weather forecast are relevant in the spot market but also influence the forward market. In winter, calm winds with strong frost and thus high electricity consumption cause high electricity spot prices, which also affect forward prices. There is a lot of weekday, intraday, seasonal structure in electricity market prices. Geilhausen et al. points out that every fossil

electricity production lead to CO2 emissions for which emission rights are consumed. These emission rights, EU Emission Allowances, are traded in the Emission Trading system in the EU. An increase in the price of emission Allowances will also increase the price of electricity. The influence of renewable energies on energy prices is substantial. There is a direct price-reducing effect in the spot market because renewable quantities are absorbed by the transmission system operators and sold on the day-ahead or intraday market. Renewables are putting pressure on prices. The factors that are relevant for the market price are oil, gas, weather, renewables, emission allowances, plant availability. (Geilhausen et al., 2015, p.135)

In-House Generation of electricity - technical

This means that the produced electricity is not fed into the public supply network but is consumed at the production site. If the required electricity can now be produced partly by photovoltaic systems at the site of consumption, the risk of increasing emission costs or grid usage fees is eliminated. Thus, in-house production hedges price risk, price volatility, regulatory risk. Geilhausen et al. states that such in-house projects may also go hand in hand with specific risks. Land acquisition, permits, approvals are necessary. The tax and other relevant tariffs can change during the lifetime. To obtain these will take substantial time and one is not sure form the beginning that the project will succeed in time. Still there is the risk that one's own photovoltaic plant does not produce like planned due to weather. The risks with the own production are relatively high. This is also the case because of technological progress. The risks are limited access to capital, budget constraints, technology obsolesce, unproven technology, closure of own plant, decrease in power prices, lack of wind or sunshine etc. (Geilhausen et al., 2015, p.209)

SWOT analysis

After the factors and their meanings, importance and interdependencies of the influencing factors are understood, the next step is the SWOT analysis from the energy perspective of our PT company. Following the SWOT analysis is using the findings of the PESTEL analysis and sorting them to the four areas.

STRENGTH	WEAKNESS
❖ Management commited to EnMS ❖ Established internal team work ❖ Well developed research cooperations ❖ Lobbying network ❖ Employee with environmental awareness ❖ Important role of PT in reaching climate goals	❖ Energy law not in main focus for a transport company ❖ Assets with high maintenance and obsolescence ❖ Lack of finance resources ❖ Long planning cycles ❖ Employees intensive industry
OPPORTUNITIES	**THREATS**
	❖ Possible carbon charge ❖ Rising energy prices ❖ Concession with city councils ❖ Pollution laws ❖ New transport modi, like robotaxis

Table 2: SWOT Analysis for a PT company

4.3 Results from expert interviews

For the purpose of this thesis, two expert interviews were conducted. The first interview was with Frank Steinhorst, Head of Infrastructure at Hamburger Hochbahn (HH). HH is the operator of four metro lines and many bus lines in the city of Hamburg. Frank Steinhorst is responsible for the complete infrastructure including all buildings, sideway facilities, electrical networks and equipment, safety and passenger's information systems. He is involved in energy management since many years in different roles, from being a member of the energy team to taking decisions as a manager.

The second interview was performed with Ignasi Oliver Gonzalez, Director of the network circulation systems at Transports Metropolitans de Barcelona (TMB). TMB is the operator of 160 trains and 1.150 buses for the city of Barcelona. Ignasi Oliver Gonzalez is responsible for maintenance and projects in railway installation. He is a driver of digitalization and automatization processes within TMB.

The most interesting findings from the interviews will be used in this thesis. Here is an overview to the relevant topics.

Energy policy – motivation and communication

The position of Hamburger Hochbahn is the one of a driver for climate and resources protection and a role model in the city. It is the clear company vision to reach climate neutrality till 2030. The company values stand for sustainable mobility and active climate change actions. The motivation has shifted from a focus on cost saving to an environmental focus in recent years. TMB`s energy policy is to improve in terms of productivity and competitiveness and secondly, to support the towards climate change efforts. Both interviews confirm the motivation for PT companies described in the theoretical part 2.4..

Stakeholders

The stakeholders have expectations regarding the priority of energy-related topics from the city council, employees and the public addition to the stakeholder analysis in 4.1, TMB provide a result from a survey showing that more than 89% of citizens are concerned about climate change and 80% of passengers believe, that TMB is making efforts to improve the quality of environment (Gonzales, 2020).

Energy team and communication

The teams are built on a long-term basis and now include experts from the fields of technology, environment, IT, legal department, procurement, communication. Energy related training courses are organized for staff in these units. CEO is involved and support strongly the efforts (Steinhorst, 2020).

Communication of efforts and results is seen as an essential part of the EnMS with increasing importance. Information on energy projects is part of the annual company report and press releases. Particular KPIs are open to public. Regular energy related posts appear in social networks. Internal communication takes place on the intranet.

New Ideas for energy efficiency and their evaluation

The generation of idea comes from different channels. Energy audits, energy teams, employee suggestion system, international working groups (Steinhorst, 2020). Benchmarking within international associations like UITP, Nova and Comet are a valuable source of knowledge (Gonzales, 2020).

An evaluation of the measures should be performed considering various aspects, not just costs. Innovation power counts additionally to environmental aspects and must be supported. When implementing new systems and solutions all energy related aspects should be take into consideration (e.g. waste heat of electrical bus chargers).

Recent energy efficiency projects

Both interviews report recent projects in the field of braking energy recovery, lighting, eco-driving, electrification of bus depots, charger installation, replacement of heating systems. The details are displayed in the following figure:

Train operation	Efficient automatic train operation driving mode
	More efficiently regulation of HVAC on trains
	Detailed monitoring of energy consumption of each train
	Installation of braking energy recovery systems
Buildings	Replacement of old heating systems in buildings
	Lighting automatic control systems incl. sensors
	Replacement of fluorescence tubes by LED tubes in buildings
	Adjustment in the operation of station equipment like elevators
	Installation photovoltaic panels in a car park and bus depots
Clean fleets	Use of electric vans and car fleet for maintenance departments
	Installation of chargers in workshops and office buildings
	Electrification of bus depots for electrical buses.
	Installation of chargers in final stops of some bus lines
	Trial on use of hydrogen buses
Others	Implementation of a global energy management system (ISO 50.001)
	Increasing energy meters and overall monitoring system

Table 3: Examples of recent energy savings measures (Steinhorst, 2020), (Gonzales, 2020)

Monitoring and Reporting

monitoring the electricity and fuel consumption for the passenger service has a greater interest and long tradition. The consumption of buildings such as heating and cooling is becoming increasingly important these days. Numbers of energy meters is increasing, and new monitoring systems are being developed.

KPIs are mostly reported annually. There is obligation from city institutions. The figure KWh/capacity km is the most relevant for the energy performance of the transport system. New KPIs for building should be developed. Weekly and monthly monitoring is carried out for special projects such as the energy recovery system.

Use of Renewable energy

So far, only small projects have been realized. The installation of photovoltaic modules is already planned in the future. Especially with the connection to new bus parking spaces. Tunnel geothermal energy is being investigated but not yet implemented. The electricity is purchased today comes from renewable energy sources. Since the energy market liberalization the procurement of energy is more complex (Steinhorst, 2020) and joint tenders are one possibility to reduce the costs for the company (Gonzales, 2020).

Future Topics

Even in a public transport company, the young employees show strong interest in environmental impact of the company and the high significance of this topic in a PT company should be actively used in the competition for the best professionals in the human resource market – employer branding (Steinhorst, 2020).

Digitalization and automation in general enable further energy savings. For example, the energy consumption of each train can be easily monitor with new IT technology. The light control and new sensors can reduce the number of operating hours with same service quality.

5 Draft of energy policy and guideline for an EnMS

The research on this thesis topic has conducted different steps and have provided the author with new facts into energy in PT. With this knowledge from literature, EN 50001 about EnMS, research projects and literature about PT, performed analyses and expert interviews, all is ready to answer the research questions and design a draft of an energy policy for a PT company. It shows a road map and gives a comprehensive overview of steps to take and issues to consider for a PT company that wants to work intensively on an EnMS. Following are suggestions and examples from the author how to proceed:

The first step is to formulate the mission statement of the company to define the clear direction in energy related issue. A statement can contain following texting:

We aim to reach climate neutrality by 2030 and increase our energy efficiency by 20%.

The commitment from the CEO level and the first management level is a key factor and therefore a must from the start. The next step is to formulate an energy policy that affects relevant aspects. Author's suggestion is following example:

Energy policy

Our energy policy goal is to continuously improve energy-related performance and reduce our CO2 emissions. This includes increasing energy efficiency and reducing specific energy consumption within the entire company as well as using all possible renewable source within company's reach. Furthermore, we aim to be a role model and active driver in the city regarding efficient energy and resource use by means of system integration and coupling, supporting our position of being a sustainable mobility provider. We are gradually introducing an energy management system for the structured implementation of these energy targets.

An essential part of the energy management system is the target tracking by all employees and the foresighted cooperation with our energy-relevant suppliers and partners. We therefore attempt to continuously expand internal and external communication in this area.

The regular analysis of the energy consumption and the internal energy distribution in connection with the evaluation of the external and internal influence factors leads to the development of energy efficiency-promoting goals. The implementation of these goals will lead to the long-term optimization of our energy performance indicators. For this purpose, an action plan is drawn up with timeline and priorities. The necessary human and financial resources are provided by the company management. Individual projects are complemented by the energy-efficient design and maintenance of energy-consuming systems as well as a modern procurement process.

In order to make success measurable, we will perform a regularly detailed monitoring and develop a meaningful key figure system. Based on this data, the company's goals for a sustainable and future-oriented service are regularly assessed.

We are also regularly reviewed and ensure that relevant legal obligations and other requirements are met in order to meet or even exceed legal requirements.

An energy management officer and an energy team will be appointed to set up and monitor the application of the energy management system. The company's employees are obliged to comply with the regulations of the energy management system and to cooperate in its further development.

The EP need to be translated into actions. The main tasks related to EnMS are described in following chapters. They are all part of EnMS with significant influence on the development and results of the EnMS.

5.1 Economical focus

Active portfolio management in energy procurement

Managing energy price risk is a part of an EnMS. The liberalization of energy markets in EU make it possible for a large energy consumer such as a public transport company to actively take part in the market and not just to agree a fixed price with a supplier. The basis for the procurement strategy is a solid energy demand forecast for the next 2-3 years. The most important KPIs, the planned capacity, changes in the infrastructure and new service expansions can be named as examples of considerations for calculating the future energy demand.

For the electricity demand forecast, the main energy source in PT in cities, the data should build a load curve in hourly time range. To manage the risk and secure the budget, buying on the market can start already 2-3 years in advance, whereby partially available annual contracts in standard quality and size are partially hedged. The residual demand curve can then be covered by short-time monthly and day-ahead products with precise demand forecasts. The final energy price is then a mixture of the long-term hedging products and the short-term products. This procedure allows companies to hedge market price fluctuations and still offer enough flexibility to meet changing demand. Procurement should be done to fix the energy budget according to the company's risk policy.

Link to cost elements based on regulations

As shown in Figure 8 the energy price procured for a PT company consists of more elements than the energy market price (commodity price). Understanding these components is a task within an EnMS. This expertise can help to find ways to reduce additional costs by i.e. monitoring the peak demand in every feed and looking for peak shaving measures in order to reduce the tariffs associated to peak power. Another advantage is to monitor the fixed costs for the feed-in point of deliveries and to find a solution together with the energy team to adapt the energy supply network on the company side and to reduce the number of feed-ins.

This knowledge is also useful to analyze the cost effects coming from new laws and regulations in advance. In general, legal expertise for interpretation, following and influencing development of new law and regulation is also part of the EnMS, which is becoming increasingly important due to new development on the European level (see 4.2 Macro- economic Analyses (PESTEL)).

Demand planning and budgeting

Historical energy consumption, KPIs as well as all available information about the future service (kilometer) and changes in the system are essential for upcoming demand planning. The results need to show the energy amount, mostly in kWh, for the next 2-6 years. A calculation of all price components is necessary to assess the future yearly energy costs.

Dedicated budgets for improvements in energy efficiency and for pilot projects, testing new technologies or approaches could be beneficial for progress in EnMS. This could also include dedicated budget for the installing renewable energy sources and related studies. The screening the funding programs could bring additional budget support in form of subsidies for energy related topics. While some administrative effort is required, this funding source should also be pursued and used due to positive effects in collaboration and company's brand image.

5.2 Organization and Communication

Energy team composition

A successful EnMS requires a team of experts to keep it running. As described previously, the tasks and drivers for energy consumption and costs have different causes and this means that a multidisciplinary energy team needs to represent these characteristics. Therefore, the teams should consist of representative from the following departments: environment, procurement, infrastructure, vehicles, operation and training, legal advice and communication.

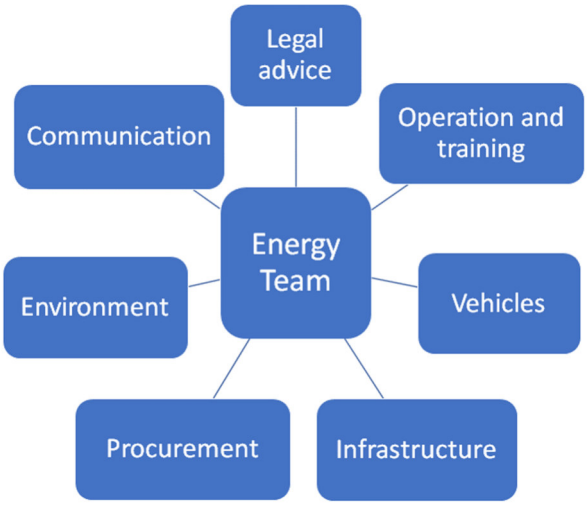

Figure 11: Examples of recent energy savings measures

All members of the team need to partly understand the involvement of the other colleagues and acquire a basic energy knowledge. All team members are multipliers of energy policy and energy knowledge in the company. The energy team can also suggest and organize special energy related trainings for department employees. The content of the trainings can be technical developments, changes in regulations, eco-driving or motivation courses for changing attitude towards energy savings.

Communication to internal and external stakeholder

The list of relevant stakeholders (see 4.1 Stakeholder Analyses) is long. Positive communication about sustainable achievements is important for both internal and external parties. Publication on the intranet can motivate employees in general to participate in EnMS. A blog reserved for energy related topics could introduce a new information channel.

Opportunities to find new ideas for energy savings

With more measures implemented, it becomes more difficult to find new ideas for improving the energy efficiency in an existing system. The following additional sources were identified in this work:

- **Energy team** –good teamwork ensure that the overall energy consumption and dependences are well understood and the findings are shared. Continuous efforts and regular reporting show the potential for improvements.
- **Employees** – they are important stakeholders and their new ideas based on their observation, special interest or knowledge, can make a significant contribution and the feeling “WE” can all bring a positive change, beneficial for the company culture in

general. Energy challenges or similar events in selected parts of the company can bring new information and commitment for energy savings.

- **External collaboration** – new knowledge from outside the company, be it from industry, energy consulters, research institutions, innovation hubs or other PT companies is a valuable source of new ideas and expertise. Cooperation can take in different forms – joint research projects, benchmarking initiatives or just regular exchange of experience.

5.3 Efficiency focus

The energy consumption of a public transport system is very complex, as described in Chapter 2.4 Energy efficiency in public transport and therefore, the opportunities to save energy are very numerous. Further examples of energy efficiency measures are mentioned in the interviews (see Chapter 4.3). Here in this chapter some of the most important trends will be described.

Energy recovery systems

Installation of energy recovery systems (see chapter 2.4) can be seen as a part of smart grids efforts. The losses in the rail systems are reduced in this way and the integration between the individual parts of the grid increases. When installing an inverter system, there is a new flow of energy in direction DC rail network to the AC network of station supply, which connects these two parts in a new way. Special requirement for integration due to rail safety reasons cause higher costs comparing to the non-rail sector. However, the durability of the rail infrastructure and the high potential of energy savings due to the service frequency support the decision to use this kind of technology. In order to optimize the advantages of the energy recovery systems, intensive monitoring is recommended to understand the interdependences in the supply system (see Figure 3) and determine the best settings and fine tuning (i.e. voltage and current settings). Feeding back to the public grid is not economically advantageous and should therefore be avoided. As a result, i.e. new research into additional use of temporary storage may be the next step to ensure the best utilization. Details on monitoring the operation of this type of system are given in Chapter 5.6.1.

Smart Buildings

Even if the share of energy in buildings for a PT company is only 30% (Gonzales, 2020), it is still very essential SEU and very important towards decarbonization. The goal when building an eco-design for metro stations, depots and workshops is to minimize their environmental impact during operations. The technological improvement of technologies such as LEDs, is one aspect. The operational settings are still the most relevant factor because it can reduce

the operating time and the load. The operating time can be further reduced by installing presence detectors. The investment cost for heating pumps, heat recovery systems are decreasing with economy of scale and are therefore more attractive and affordable to install today than some years ago. When planning new energy supply systems in buildings, the entire potential of heat waste must be optimally used to consistently reduce all energy losses. The planned integration in the charging infrastructure for electrical vehicles also need to be considered in the energy supply, metering and the waste heat recovery.

The use of renewable energy sources such as photovoltaic panels and geothermical energy should be investigated in every planning and used where possible. Replacing old heating and cooling systems is a great chance to install modern efficient systems using new technology and control systems. All these efforts lead to more automation control in the buildings and more data produced and stored. The energy managers and facility managers have to work together to make optimal use of these data and control systems and to ensure energy efficient building operations.

Electrification and Smart grids

The efforts to establish clean vehicles in the fleets of PT companies lead to new tasks in many departments and also in the energy team. The need to search for the best economical solution in a short time offers the possibility to integrate the charging infrastructure to the existing strong electrical rail infrastructure. An intensive metering should be installed to separate the operating modus and have valid consumption data for all vehicles.

The importance of the electrical supply grid is therefore increasing, and more efforts and personal resources should be put in the automation and monitoring of these systems. Minimizing transmission losses and ensuring optimal operation condition is an important task and also a challenge with the increasing number of components. The smart operation of all the transport service will requires comprehensive load management considering different aspects in the operational reliability and performance.

5.4 Evaluation of energy saving measures

5.4.1 Example of a multi-criteria analysis for energy related decisions

As soon as relevant energy saving measures have been identified, it is beneficial to characterize and evaluate them at a high level in the broader sense according to their effects on the company. The basic criteria such as investment, energy and CO2 savings can be extended by individual criteria that are chosen by the company corresponding to their internal priorities and goals.

The use of a multi-criteria approach will help to facilitate the comparison between the different measures and support the discussion within the company between the departments involved and the various parties involved. The results from such a matrix can be used as a starting point for an internal discussion and hopefully lead to a unisonous decision on the prioritization of the next steps in to save energy.

Table 4 shows an example of such a matrix and evaluation. First, all relevant saving measures – results from energy audits, internal projects groups or benchmarking – are listed. The evaluation criteria are then listed and specified as beneficial or non-beneficial for the planned measure.

In the next step the criteria are weighted according to their importance for the overall impact. Every measure receives a rating from 1 to 5 showing the impact towards the criteria. The overall score is calculated as weighted average of the individual rating evaluation and each weighting criterion, taking into account the beneficial effect of the criteria. By selecting the actions with the highest global score, a short list of actions to be implemented first can be created.

Saving Measures / Criteria	non beneficial Investment	beneficial Life Cycle	non beneficial Mainten. Cost	beneficial Energy Savings	beneficial CO2 Emission reduction	non beneficial Complexity	beneficial Environme-ntal image	beneficial Sector implement-ation	Overall Score	Rating
Weighting	30%	10%	10%	15%	10%	10%	10%	5%		
Use of invertors and storages	4	4	1	3	3	3	3	2	2,45	8
Led Lights	1	2	0	2	2	0	4	4	3,5	1
Solar panels in buildings and depots	3	4	2	1	3	2	5	3	2,7	6
Training of drivers	1	2	1	1	1	2	3	2	2,75	5
Switching off function for parked vehicles	2	4	1	2	2	3	1	3	2,65	7
Automatic control of the lighting in buildings, light sensors	2	4	2	2	2	3	3	3	2,75	3
Efficient driving mode in train operation	2	4	1	2	2	3	2	3	2,75	4
Improvements in a automatic control of ventilation in buildings	1	3	2	2	2	1	2	3	3,05	2

Table 4: Example of a matrix for prioritizing savings measures

The eight criteria used in the example can be briefly described as follows:

Criteria linked to costs are:

- **Investment** – is a non-beneficial criterion – the higher the score, the higher the negative effects. The initial investment required to implement the measure is taken into

account. The additional cost-related efforts due to the special railway regulation must be assessed together with the increasing complexity.

- **Life Cycle** – it is a beneficial criterion – the higher life cycle has a positive impact on the realization since the saving effect lasts longer without further actions.
- **Maintenance Cost** – is a non-beneficial criterion – the higher rating means that this action causes maintenance cost during the life-cycle (e.g. regularly adjustments, cleaning, replacement of device parts…).

Criteria linked to environment are:

- **Energy Savings** – it is a beneficial criterion – the yearly energy savings in daily operation are assessed in this field. In the matrix it is used as a qualitative criterion and the saving is compared with the overall consumption and in comparison with the other possible actions.
- **CO2 Emission reduction** – it is a beneficial criterion – this criterion is linked to the amount of CO2 that is saved by the implementation of this measure. The rating is linked to energy savings, but measures linked to production of renewable energy sources or the use of biofuels will have a greater impact on CO2 than energy savings.

Criteria linked to other priorities are:

- **Complexity** – is a non-beneficial criterion – this score shows how this action influence the complexity of the overall system. In most cases, the complexity increases when new device is introduced into the system – such as invertors or storages – which means that new specialist knowledge within the company and eventually more control systems are required to benefit from the new device.
- **Environmental image** – it is a beneficial criterion – the impact of this action on green image of the company can be assessed with this criterion. Some projects are better for the public relation than others. This criterion can be used to control the importance of communication with stakeholders.
- **Degree of sector implementation** – it is a beneficial criterion – this criterion expresses the novelty of the solution comparing to standard in the industry. Since new innovation also means a higher implementation risk, the high score means more standardization and proven integration.

5.4.2 Example of an economic analysis of an energy saving measures

The following paragraph provides an example of economic analysis for an energy savings investment. Compared to the multi-criteria decision matrix used solely for qualitative rating, the

economic analysis should determine the profitability of an investment. It is suitable for more detailed analysis and requires more information about the project under investigation.

The initial input parameters are as follows:

- Investment at the beginning of project in year 0
- Operating costs during the lifetime
- Yearly energy savings in kWh
- Energy price in EUR/MWh
- Factor for CO2 savings in g/kWh
- CO2 price in EUR/ton
- Discount rate in %

	Cost	Cost	Benefit	Cash Savings	Benefit	Cash Savings	
Year	**Investment**	**Operating Costs**	**Energy Savings**	**Energy Price 180 EUR/MWh**	**CO2 Savings 200 g per kWh**	**CO2 price 50 EUR per ton**	**Cash Flow**
	EUR	**EUR**	**kWh**	**EUR**	**ton**	**EUR**	**EUR**
0	-10 000						**-10 000**
1		-500	15 000	2 700	*3*	150	**2 350**
2		-500	15 000	2 700	*3*	150	**2 350**
3		-500	15 000	2 700	*3*	150	**2 350**
4		-500	15 000	2 700	*3*	150	**2 350**
5		-500	15 000	2 700	*3*	150	**2 350**
			75 000	**13 500**			**1 750**
						Discount Rate	3%
						Net present value in EUR	740 €
						Internal Rate of Return	5,63%

Table 5: Example of a financial evaluation of investment in savings measures

The yearly energy and CO2 savings for the project time as well as operating costs, market price for energy and CO2 valid period are input parameters to calculate the cash flow, the internal rate of return and the net present value. Representative values were selected for this demonstration. The inclusion of CO2 cost into the calculation is optional. It supports the importance of emissions as a future cost element. The price of a ton CO2 within such economic analysis can deviate from the market price of CO2 for European Emission Allowance as well as from possible CO2 penalties or taxation. To overcome market price fluctuations or for the

reason of introducing a real CO2 price or an internal CO2 price, a company's own CO2 price may be used for the economic assessment.

These internal CO2 prices should be above the market prices. To support the decision, the net present value and internal rate of return are calculated and should be positive. The results can be compared to other energy savings projects and help prioritize profitability. This is a way to make CO2 part of the economic assessment. Within the following calculation a CO2 fee of 50 EUR/ton is used. This fee can be an external or an internal fee. With an internal fee, it is possible to assess the value of CO2 savings at a higher price than the CO2 market or possible CO2 taxation does. Projects which save more CO2 will get higher profitability with higher CO2 prices.

5.5 Environmental focus

Energy mix

The so-called origin of energy has no influence on the energy consumption but on the amount of emissions, mostly CO2. When purchasing electricity, the energy mix is one of the issues to negotiate in a contract with one's energy supplier. The focus should be on supporting to build new renewable production capacities in Europe, and the purchase of green certificates of origins can contribute to it. A similar decision concerns the share of biofuels in liquid fuels. National laws set a minimum value and the PT company may choose to increase that percentage to set an example and support the local biofuel production.

Integration of Renewable Energy

Metro stations, depot and workshops could be designed to minimize their environmental impact during operations. The eco-design can include low energy consumption ventilation and heating systems with ground source heat pumps and heat exchangers. Geothermal loops can be installed in the tunnels and deep station walls and cover the heating and air conditioning needs in the station. The waste heat from technical devices is a particularly important source of energy and should be used.

Public transport companies are paying increasing attention to the installation of photovoltaic solar modules, which is partly due to the increasing rentability and in combination with the planned introduction of electric bus fleets. The focus is on the consumption of the generated energy on site and the usage for all electrical equipment in the depot including the charging infrastructure. When installing photovoltaic solar panels in the existing rail infrastructure, i.e. on the roofs of the metro stations and workshops, there are some restriction in addition to rentability. The stability of the roofs and the presence of many roof openings for ventilation and natural light can be a challenge for a successful implementation. The existence of large

electrical supply networks within the transportation systems as well as advanced process control systems are enablers for this integration.

5.6 Monitoring and KPIs

In order to follow the development of company`s energy performance and to achieve the goals set in the energy policy, a number of performance indicators should be defined and regularly calculated and reported.

Reporting schedule should be reasonable, at least once a year for all figures and for some seasonal parameters on a monthly basis. The author proposes to create three groups of indicators and to further develop them according to the changing goals and priorities in the company.

Some operational data that are used as unit of transportation for the calculation of energy related KPIs are:

- **Number of passengers** using the transport mode. This figure can be determined from the passenger counting systems in each vehicle or from the information in access control systems.
- **Passenger capacity kilometer** - defined as vehicle kilometer multiplied by the authorized number of passengers in the vehicle. Usually, the authorized number of passengers is calculated as sum of all seats, with four persons added per m2 standing.
- **Kilometer of network** defined as the length of the installed network in km
- **Weather condition** - further data such as hourly temperature in relevant areas, heating and cooling degree days.

1. KPIs related to energy costs [KPI_EC]

[KPI_EC_1] Share of energy costs in relation to total operating costs of the company [%]

Data source: Information about the yearly costs comes from energy billing and controlling department.

[KPI_EC_2_A,B,C,D] Total energy cost divided into four categories and the share of each compared to total energy costs- commodity price [A], grid tariffs [B], renewable energy contribution by law [C], other energy taxes [D] [%]

Data source: Information about the yearly costs comes from energy billing and the shares of each element are calculated. The proportion and the changes over time show the most important areas to focus on in the next activities.

[KPI_EC_3] Commodity **p**rice for electricity, only the component related to the electricity market [EUR/MWh]

Data source: This figure shows the development of the average energy market price paid by the company in the reporting year and comes from energy procurement.

[KPI_EC_4] Commodity price for diesel [EUR/l or EUR/MWh]

Data source: This figure shows the development of the average diesel price paid by the company in the reporting year and comes from energy procurement. As the bus fleet can have different propulsion systems, so other fuels like natural gas are possible too. Best to establish a KPI for every energy source.

2. KPIs related to energy consumption and performance [KPI_EP]

[KPI_EP_1] Total energy consumed per total number of passengers in the time period. [kWh/passenger]

Data source: This figure can be calculated in total or for each transport mode, also depending on the determination of passenger numbers. It shows the energy performance in relation to usage of the transport system. Flexibility of the system with offer /demand adjustments can be monitored with this number.

[KPI_EP_2_ A, B, C, D] Traction energy consumed per 1.000 capacity km – for each modus [kwh/capacity km] M

Data source: Traction energy is the energy used for the movement of vehicles. This indicator has to be calculated for each transport modus separately. For metro [A] and tram [B] operation these data come from the substations, in case of electrical buses [C] the relevant data comes from charging points and for the diesel buses [D] it is the fueled amount.

[KPI_EP_3] Stations' energy consumption [kWh /Station]

Data source: Energy consumed by all equipment in all stations. Instead of number of stations, the network kilometer can be used too. It will include the all energy sources for any purpose including heating and cooling.

[KPI_EP_4] Workshops and depots' energy consumption [kwh/number of vehicles parked]

Data source: Energy consumed by all equipment in the workshop and depots. Instead of number of vehicles, the m2 in the facilities can be used too. It will include the all energy sources for heating, cooling and all equipment. Preferably, this indicator has to be calculated for each transport modus separately.

[KPI_EP_5] Office buildings' energy consumption [kWh/number of employees]

Data source: Energy consumed by all equipment in the all office buildings. Instead of number of employees, the m2 in the facilities can be used too. It will include the all energy sources for heating, cooling and all equipment.

[KPI_EP_6] Recovered brake energy in subsystems like invertors or storage [kWh]

Data source: Amount of energy recovered in the rail system by additional recovery systems. The natural exchange between an accelerating and braking vehicle is not included in this indicator. The new data from the train digitalization efforts could be used to feed a new indicator.

[KPI_EP_7] Transmission loss in electrical supply networks [%]

Data source: the control systems provide a wide range of data which can also be used to calculate the energy losses in the system. I.e. the share of energy feed in from public network compared to the energy transmitted to the internal supply network.

[KPI_EP_8] Energy consumption of service vehicles [kWh/vehicle km]

Data source: This figure shows the energy consumption of all vehicles not used for passenger's service, but for the operation of the system. Cars, trucks, light vehicles or special vehicles. It is the fueled or charged energy to the vehicle (tank to wheel).

3. KPIs related to Emissions [KPI_EM]

[KPI_EM_1] - CO2 in electricity mix [g/kWh]

Data source: Energy procurement. Quality can be order through energy supplier on a yearly basis.

[KPI_EM_2] - Share of renewable energy produced on site [%] compared to the overall energy consumption of buildings

Data source: Internal metering in company's facilities. Data from Renewable energy production are summed up [kWh/year]. Examples of data are generation of electricity in photovoltaic panels and heating pumps. Yearly evaluation is a good start. Because of seasonality in the energy generation monthly indicator is also very significant.

[KPI_EM_3] - Biofuel share [%] in diesel

Data source: the portion of biofuels compared to the total fuel used.

[KPI_EM_4] - Share [%] of clean buses in the bus fleet.

Data source: number of buses clean in relation to number of all buses. Alternative kms of clean buses in relation to all bus km. The definition "clean" is according to Clean Vehicle Directive (see 4.2.)

[KPI_EM_5] - Share [%] of clean vehicles used in the company.

Data source: The company car fleet is in focus here. Number of clean cars in relation to all cars. The definition “clean” according to CVD. In later development the figure can be adjusted also to lorries and special vehicles.

The following picture summarizes all described performance indicators in three groups offering a full picture of the monitoring figures.

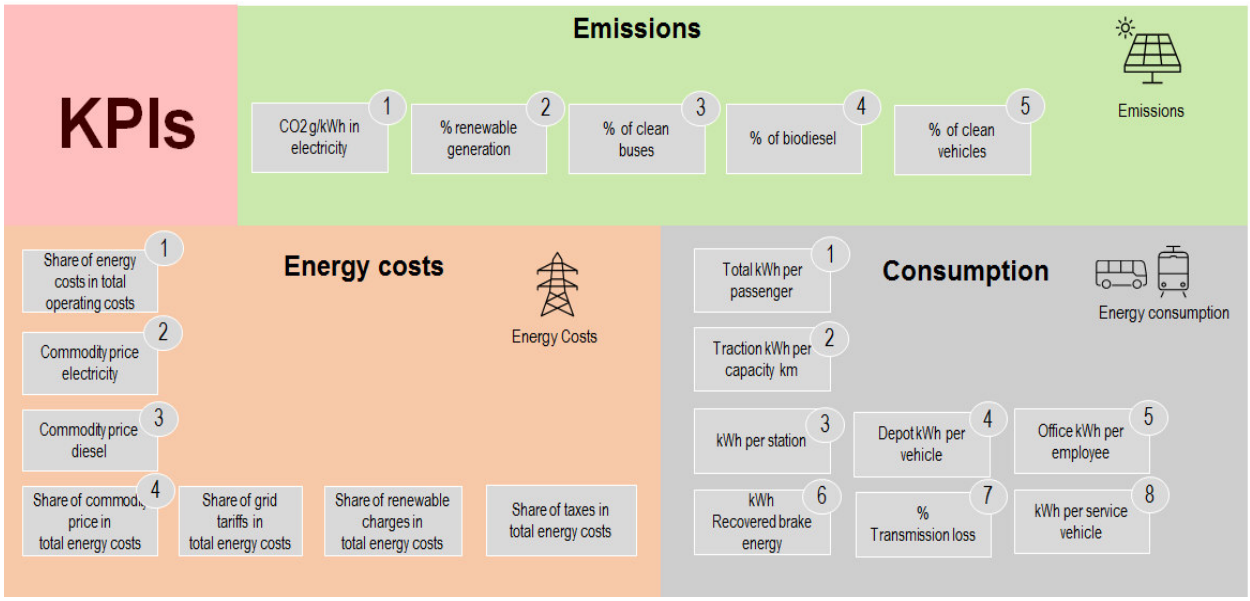

Figure 12: KPIs Overview

In the yearly report a chapter on the development of the number of people in the company involved in energy related topics could be found, such as, i.e. “green jobs”. Other relevant energy related employee training and support activities could be listed. In addition, participation in research projects and cooperation in energy sector could be published.

5.6.1 Monitoring of energy recovery systems

As previously described, the close monitoring for this new technology is essential to maximize the benefits of these systems. The suggested time interval for monitoring is at least weekly monitoring of its proper functioning combined with a monthly detailed reporting. This monitoring is related to [KPI_EP_7].

The relevant data are, on one hand, the spontaneous values of feeding into the station grid in order to recognize the maximum power and the duration of the relevant braking period. This is the best information about the function of the system. On the other hand, the load curve in 15 min time range is an economic implication, since these values are relevant for billing with energy supplier on the side of the public grid. In addition to the load curve data, following aggregated data can be useful for monitoring:

- Operating hours [h] - Number of hours with infeed power greater than zero
- Service availability [%] – number of service hours by the inventors compared to the total service time of the metro system
- Daily, weekly, monthly energy recovered [kWh] – amount of energy recovered = feed into the AC network in 24h, 7 days, 1 month of metro operation

These KPIs enable the comparison between the time periods and different locations or lines. The energy flow simulation can be used to verify the amount of recovered energy and compare it to the theoretical values of a network simulation. In addition, the ratio of the amount of energy recovered and the number of trains in operation can help to understand the system efficiency and support the decision for the next projects (e.g. position in the network, size).

An expanded attention needs to be put on the surplus energy that cannot currently be used in the station power network, mainly due to seasonal differences in the station load. In this case, the energy is fed to the superordinate public grid. Monitoring of this figure shows whether additional measures such as load shifting or batteries installation should be taken into further consideration.

6 Discussion and Future prospects

It is crucial to operate a comprehensive EnMS and not to leave out important parts. Only the understanding und interlinking of all tasks will ensure the maximum benefit from the EnMS. Setting it up is one task, keeping it running is another challenge.

In author's opinion, the company and the energy team should always focus on the useful and practical side of energy management. No system is perfect and the aim of all the activities is also to support the daily operations. The long-term success is only guaranteed if energy saving efforts are fully supported. Communication of EnMS achievements and highlighting synergies between different departments support the acceptance of the energy management and supports the positive culture shift towards innovation.

The rationale of energy savings, even for a public transport company, is most obvious for all stakeholders. However, there are still some obstacles for to energy policy actions. The most evident is the need to make investments to start the projects and replace existing systems by modern ones. The long-life cycles make it more difficult to realize adjustments in existing systems. Other aspects that mainly apply for safety and customer-oriented systems like PT is the significance of marketability of the products and solutions used to save energy. The implementation of the latest technologies in the rail industry requires comprehensive test and trail phase due to high safety standards and is therefore more expensive than in other industries. The calculation of the profitability with the actual energy costs (see chapter 5.4.2 Example of an economic analysis of an energy saving measures) can still lead to negative prospects. As the forecast of future energy prices and regulations is uncertain, the strategic goals and alternative pricing of CO2 components can support the rentability and the investment decision.

In the author's experience, a well-functioning EnMS means good communication and will have a positive influence on the overall company culture and performance. This thesis is intended to motivate all entities to mobilize resources for an EnMS, which will have overall beneficial effect for the company. The results - increased energy efficiency and performance - are what counts. The implementation of EnMS can vary in intensity and forms. Every company can decide whether the certification of the system according to EN 50001 offers more benefits or whether energy audits are preferred. The recommendations in EN 50001 are very helpful and provide a guideline for a systematic approach to increasing energy performance. Continuity of the efforts is indeed a must with any chosen approach.

The goal is to find the best ways to achieve excellent transport system performance in terms of customer satisfaction and passenger capacity and to combine it with top energy performance. Sure, there are some trade-offs where important features like - bright stations

with inviting lighting, vehicles with pleasant indoor temperature, high transportation speeds - contradict energy savings. Through optimization of supply and demand supported by digitalization energy performance can be improved and consequently motivate more people to use public transport instead of cars.

My recommendation for 10 golden rules for EnMS for a PT company:

1. Involve the CEO and management, inform and commit them towards energy savings. Establish an energy savings culture. Make energy a strategic priority. Motto “Energy counts!”.
2. Make energy efficiency a top priority. Motto: “What is not consumed, need not to be produced”. The focus is also on energy use in buildings and losses in systems, not just transport.
3. Build a multifunctional energy team, apply a broader focus and set up a central energy-management function to drive the activities forward. Use improved energy efficiency to outperform in overall company’s performance.
4. Use the strong rail infrastructure to integrate the charging infrastructure for other clean vehicles like buses, cars, trucks as well as renewable energy sources.
5. Use digitalization to improve energy efficiency.
6. Sep up visionary goals and develop a detailed metering as well as a robust monitoring and reporting system.
7. Make data and costs transparent. Publish and share the achievements.
8. Get involved through active communication with all stakeholder. Participate actively in development of European and national energy regulations.
9. Set up cooperation and innovation projects, including various industries.
10. Involve the young generation and use the positive green image of the company when recruiting to bring the passionate and committed changers on board. Invest in training and education.

Future Prospects

Changes in the bus fleet

In the area of emission-free buses, studies show that operators are faced with considerable additional costs for vehicles and the infrastructure to be built due to the level of maturity and the associated low availability of buses. There are currently still problems with the availability and reliability of the zero-emission vehicles. Due to the changing propulsion system, the refueling infrastructure - charging stations and hydrogen filling stations - must also be adapted. In case of electric buses, the feeding strategy will be essential to determine the rentability of the bus service in comparison to other systems. Determining battery size and the technology will represent a significant market differentiation between the bus manufactures and the

different needs and approach of the bus fleet operators. The power grid must be adapted to the future loads in the depots. Adequate timeline and space must be planned to create the appropriate infrastructure.

Due to urban rail systems such as trams and metros, the public transport in most major European cities is already today powered largely by electricity. The planned electrification of the bus fleet and other vehicles (cars, light-duty vehicles, trucks) will lead to an increasing electricity demand for PT companies. Increasing dependence on electricity rises the risks of the energy market, and new solutions for the design of fallback systems and reactions in event of supply shortage or blackout have to be found. In addition, the distribution of the load is becoming even more seasonal (heating period) due to electrical heating in all electrical vehicles. It means further pressure on energy generation and supply.

Hydrogen bus fleet

The search for the clean bus fleet solution for demanding operational requirements (e.g. large vehicles, short intervals, stop and go traffic) prompted many cities to look towards hydrogen buses. There are several pilot operations in European cities, many of which are co-financed by the European research projects JIVE and JIVE 2.

Fuel cell buses provide an operating performance that compares favorably with conventional solutions. The advantages are long driving ranges with refueling times which are comparable to diesel buses. The waste heat from the fuel cell can be used for heating purposes in winter. This is a significant advantage over electrical buses, especially in cities with cold winters. In this way, fuel cell vehicles offer considerable operational flexibility and at the same time the same advantages as electric vehicles (e.g. noise reduction, smooth driving experience, fast and continuous acceleration). In addition, hydrogen does not cause local pollutants. Fuel cells vehicles only release water and completely avoid harmful local emissions (Berger, 2018, S. 16).

For the bus fleet operator, hydrogen vehicles lead to new challenges that are not only associated with new operating rules and safety regulations, but also with high costs for bus procurement and higher fuel spending. Governmental investment subsidies and reliefs in fuel taxation and tariffs are additional support schemes. The maturity of the bus manufacturing market as well as the unverified reliability and longevity in daily service are the main concerns of the operators.

Hydrogen can be produced from 100% renewable energy sources and therefore has the potential to completely decarbonize the energy use in transport. But the question is, at what cost and in what time period. The ambition to use only green hydrogen from the start of the

operations in near future will lead to higher fuel costs for public transport and will therefore slow down the roll out. But without doubt, green hydrogen is the goal for the future.

For small trial operation of a small number of buses, the hydrogen can be transported in trailers to the depot and refueled in a similar to a diesel bus. The fueling station has higher requirements for space, connection to power supply, various safety standards and regulation.

For larger fleets, there are only two ways how to manage efficient re-fueling of hydrogen buses. One is the production of hydrogen on site by electrolysis, the second is the transportation of hydrogen via pipelines that are directly connected to the depot. Both solutions are not only expensive, but also complex undertakings and require new business models and collaboration to benefit from economies of scale.

The public and passengers also need to be involved in the projects to gain their trust and resolve any potential security concerns that are often associated with the introduction of new technology. good and intensive communication is therefore essential and should be a part of every project.

Driverless metro systems

Changes in operation and technical systems aim to increase operational efficiency and reliability of the transportation system. This is an additional step in automation, and enables the further optimization of timetables and other operational settings due to the lack of drivers on board of the train. It is also an opportunity to improve the energy efficiency of the system through environmentally friendly driving, shorter stops in the stations and better braking energy recovery through an optimized timetable.

A new public transport model for the “last mile” autonomous vehicle is in focus of all modern cities. The benefits of driverless operation are very appealing and the mobility on demand could also be energy efficient if the demand and supply side are perfectly matched. Other advantageous applications of this technology could be automatic buses or trains moving in depots.

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Attachment 1: Transcript of interviews

Transcription of Interview

Interview partner: Frank Steinhorst

Interviewer: Eva Keuschnig

Date: 30. April 2020 15:00

Topic: Energy management at Hamburger Hochbahn

00:00:00-00:48:25

I: Also, guten Tag aus Wien nach Hamburg #00:00:11#

B: Ja, guten Tag aus Hamburg zurück nach Wien #00:00:14#

I: Ja Frank, wie ich dir schon im Vorfeld erklärt habe, mache ich jetzt eine Masterthesis an der Wirtschaftsuniversität Wien, im Rahmen meines MBA‘s und ich bedanke mich schon jetzt herzlich bei dir, dass du bereit bist mir ein Interview zu geben zum Thema Energie und öffentlicher Verkehr und ich möchte dich darauf hinweisen, dass ich für die Zwecke dieser Arbeit unser Interview auch aufnehmen muss und ich würde dich bitten zu sagen, dass du damit auch einverstanden bist. #00:00:41#

B: Na klar, also A, nehme ich gerne daran teil, vielen Dank dafür und B, das Aufzeichnen ist vollkommen in Ordnung für mich. #00:00:47#

I: Sehr gut, also das Interview wird dann von mir aufgeschrieben auf Papier, also transkribiert, das werde ich dir dann auch gerne zukommen lassen und die Aufnahme wird dann nicht weiter aufbewahrt. #00:00:59#

B: Alles klar, ne okay super. #00:01:01#

I: Sehr schön, also bevor wir gleich zu unserem Thema gehen, möchte ich dich gerne bitten, dass du dich nur kurz vorstellst in deiner Aufgabe bei der Hochbahn. #00:01:10#

B: Ja, also mein Name ist Frank Steinhorst, ich bin bei der Hamburger Hochbahn AG tätig. Die Hamburger Hochbahn AG selbst ist in Hamburg das größte Nahverkehrsunternehmen und verantwortlich für das U-Bahn-System mit seinen vier Linien. In Hamburg gehört dazu auch ein Großteil des Bussystems, welches die Hochbahn dort betreibt und verantwortet und meine persönliche Funktion ist dort Bereichsleiter „Infrastruktur“. Bereichsleitung „Infrastruktur“ heißt bei der Hochbahn, dass ich dort für die ortsfesten Anlagen und Systeme verantwortlich bin. Das geht los für das U-Bahn-System, mit der Zugsicherungstechnik, den Energieanlagen, dem Facility-Management mit, den bautechnischen Dingen der U-Bahn-Haltestellen, Werkstätten,

Betriebshöfen und es gehört auch der Bahnbau, mit Tunnelanlagen, den Gleisen und den Weichenanlagen dazu. Also alles was ortsfest ist, ist Bestandteil. Aufgabe ist die Instandhaltung (Wartung, Inspektion, Reparatur und Erneuerung) dieser Anlagen und Systeme. Bei den Großprojekten ist die Teilprojektleitung für die ortsfesten technischen Anlagen, das heißt also bei dem Bau der U-Bahn-Linie 4 dem Bereich Infrastruktur zugeordnet. Bei einer Erneuerung der Bestandsanlagen, wie z.B. eines Stellwerks liegt die Gesamtprojektleitung in meinem Bereich. Das Gleiche gilt für den Bus- und Verwaltungsbereich, alle ortsfesten Anlagen, Systeme und Liegenschaften sind dem Bereich Infrastruktur (2:29) zugeordnet. Der Bereich selber hat ungefähr 640 Mitarbeiterinnen und Mitarbeitern. Im Nebenamt -bin ich noch einer der stellvertretenden U-Bahn- Betriebsleiter der Hochbahn. Das zur Kurzvorstellung. #00:02:51#

I: Ja, das ist wirkliche jede Menge Aufgaben im Infrastrukturbereich. #00:02:59#

B: Ja, vielleicht ergänzend, weil es mir durch den Kopf schießt und für das Interview vielleicht nicht ganz ohne Interesse ist: ich selber, von der Ausbildung bin Elektroingenieur und deswegen dem Thema Energie besonders zugewandt, weil es auch aus meiner eigenen Biografie einfach passt. #00:03:19#

I: Ja, das trifft sich dann wunderbar. Ja, also dann gehen wir vielleicht gleich zum Thema Energie? Also ich habe meine Fragen an dich in vier Bereiche aufgeteilt und würde gerne mit dem Bereich Energiepolitik oder Energiestrategie beginnen und wollte fragen, als erstes, welchen Stellenwert diese Energiepolitik bei der Hamburger Hochbahn hat. #00:03:45#

B: Ja, also einfach gesagt könnte ich jetzt sagen einen hohen Stellenwert, aber das wäre natürlich zu einfach und zu platt. Also, der Hochbahn ist es im Grunde genommen seit vielen, vielen Jahren sehr wichtig das wir verantwortungsvoll mit dem Thema Energie umgehen. Das ist mit eines unsere Unternehmensziele. Das heißt also, der Hochbahn ist sehr bewusst, dass ihr Energieverbrauch auch Auswirkungen auf das Klima habt. Damit hat das Thema Energiepolitik eine hohe Bedeutung für die Hochbahn und ist auch für den Klimaschutz wichtig. Zu einer guten Energiepolitik gehört es für die Hochbahn auch dazu die Energieeffizienz zu steigern. Nur wenn sinnvolle Einsparpotenziale frühzeitig erkannt und umgesetzt werden, kann ein zukunftsfähiger Umgang mit Energien gestaltet werden. Deswegen, möchten wir dort auch ein gesellschaftliches Vorbild in Hamburg sein. Dieses wird auch dadurch deutlich, dass wir schon seit vielen Jahren versuchen in übergeordneten und übergreifenden in Projektteams uns mit diesem Thema intensiv zu befassen und entsprechende Arbeitsgruppen sich im Unternehmen etabliert haben. Momentan steht im Fokus der Hochbahn, für 2030 eine Klimaneutralität zu erreichen. In der Strategie HOCHBAHN 2030 hat die Hochbahn eine ganzheitliche Vision der intelligenten Mobilität für eine lebenswerte Zukunft und sieht sich als Treiber für Klima und Ressourcenschutz mit Umweltleitlinien. Somit ist das Thema Energie auch für uns eines der Top-Themen in dieser Dekade. Das wird auch durch die Umstellung des Bussystems auf Elektrobusse deutlich. Auch

die Stadt Hamburg hat hier eine klare Erwartungshaltung und dem versuchen wir gerecht zu werden. #00:05:33#

I: Ja sehr schön. Dann hätte ich noch eine kurze Detailfrage dazu und zwar, wie wird diese Energiepolitik auch kommuniziert nach intern und extern? #00:05:42#

B: Ja, also da gibt's natürlich verschiedene Wege der Kommunikation. Es gibt einmal den Unternehmensbericht. Der Unternehmensbericht ist für uns ein Papier welches, für die Öffentlichkeit, aber auch für den Aufgabenträger gedacht ist und dort versuchen wir schon sehr gut und sehr strukturiert neben den typischen betriebswirtschaftlichen Kennzahlen auch das Thema Umwelt und Klimaschutz und damit auch Energie darzustellen. Ein weiterer Punkt ist auch das Thema Pressearbeit. Das heißt also, uns ist auch sehr daran gelegen in Presseterminen über neue Anlagen und über neue Technologien zu berichten, hierbei legen wir auch den Fokus auf das Thema Energie, Energieeffizienz und Umweltwirkung und versuchen dieses greifbar in die Öffentlichkeit zu transportieren. Wir sind auch Mitglied, der sogenannte Umweltpartnerschaft Hamburg, in welcher regionale Unternehmen mitwirken, um eben auch Themen der Energieeffizienz mit zu bewegen. An dieser Stelle, sei auch erwähnt, dass wir in Arbeitskreisen VDV deutschlandweit, UITP international mitzuwirken, um zu gestalten aber auch über diese Verbände Themen öffentlich zu machen. #00:07:21#

I: Ja, also das Interesse ist groß offensichtlich. Also kommt gut an. #00:07:25#

B: Ja, das Interesse ist groß und ist auch steigend. Gerade die junge Generation, glaube ich, hat eine ganz andere Umweltsensibilität als das vielleicht ältere Generationen hatten oder haben, weil vielleicht auch andere Dinge einfach einen höheren Stellenwert damals hatten und heute sieht man es ja auch an den Bewegungen in der Öffentlichkeit, dass da auch kritischer nachgefragt wird. Wenn ich noch einen Blick auf die interne Kommunikation werfe, da ist eigentlich unser wesentliches Medium, in den letzten Jahren hat es sich da hin entwickelt, unser Mitarbeiterportal. Das heißt, das ist ein Unternehmensportal, wie so ein Intranet, Internet in eingegrenzter Form, wo auch gezielt über die Unternehmensziele berichtet wird, das heißt also auch das Thema Energie, Energiepolitik, ist dort präsent. Aber auch dort ist es so, dass wir versuchen auch mit kleinen Themen, kleinen Projekten immer wieder über das Themenfeld zu berichten. Das fängt an mit einer Umstellung der Beleuchtungstechnik auf LED-Technik die eine höhere Energieeffizienz hat, das geht aber auch weiter zu kleinen Themen wie Optimierung der Betriebsweise von Fahrtreppen es setzt sich fort bis in den U-Bahn Bereich, wo wir den U-Bahn Fahrern schon seit vielen Jahren, zum Beispiel die Abschaltgeschwindigkeit einblenden. Das heißt, das ist die Geschwindigkeit bis zu der der Zugfahrer beschleunigen soll damit er den Fahrplan einhält und nicht unnötig hoch beschleunigt vorgegeben wird. Und das wird alles über kurze, Berichte im Portal dargestellt, um dort auch entsprechend die Mitarbeiter mitzunehmen. Es wird dort auch über das öffentliche Engagement berichtet wie z.B. dass die Hochbahn schon

seit 2018 einer Initiative „United Global Compact“ beigetreten ist. Dieses ist eine Initiative in welcher sich internationale Firmenverpflichten bestimmte Werte zu vertreten. Die HOCHBAHN bekennt sich im Rahmen dieser Initiative zu Themen wie Menschenrechte, Arbeitsnormen, Umweltschutz und Korruptionsbekämpfung. Und verpflichtet sich unter anderem zur Bekämpfung von Diskriminierung und auch zur Entwicklung umweltfreundlicher Technologien und der der Schaffung eines größeren Umweltbewusstseins. Also wir sind da, glaube ich, als Hochbahn auch auf vielen Kanälen unterwegs, so würde ich mal behaupten wollen und man merkt aber auch, nochmal auf die Frage zurückkommend, ein hohes Interesse, ja nicht nur Interesse sondern Erwartungshaltung von Mitarbeitern und der Öffentlichkeit. #00:10:11#

I: Ja, sehr interessant. Ja, nächste Fragestellung wären zum Thema Energiemanagement intern. Also wie sieht das Team aus, welches sich intern mit dem Thema Energiemanagement beschäftigt oder wer ist da aller involviert? Vielleicht kann man mal in dieser Richtung ein paar Informationen bekommen? #00:10:32#

B: Das Thema Energiemanagement hat eigentlich, wenn man mal genau schaut, eine lange Historie bei der Hochbahn. Die Gewichtung des Themas hat sich verändert, es war sicherlich vor fünfzehn, zwanzig Jahren eigentlich nur betriebswirtschaftlich geprägt, dass man sich mit dem Thema Energie, Energiemanagement beschäftigt hat. Man hatte zu dem Zeitpunkt, fünfzehn, zwanzig Jahre zurückblickend, das Thema Umwelt, Umweltwirkung noch gar nicht so stark im Fokus gehabt wie das heute der Fall ist. Deswegen ist dieses Thema bei uns, unabhängig von Verpflichtungen, zum Thema Energiemanagement oder auch Energieaudit, als zartes Pflänzchen vor, wie gesagt, einem Zeitraum von fast zwanzig Jahren angefangen zu wachsen. Erstmal beginnend aus zwei Zuständigkeitsbereichen, einmal aus einem Bereich, der sich um das Thema Nachhaltigkeit kümmert, also das heißt die Kollegen waren sicherlich schon früh unterwegs bei diesem Thema. Aber die Wahrnehmung der Unternehmen war tatsächlich noch eine andere als sie heute ist. Und der andere Bereich oder Zuständigkeit sind die Kolleginnen und Kollegen, die sich um das Thema Energie, Energiebeschaffung, technische Anlagen kümmern. Das heißt dort wo Energie gebraucht und verbraucht wird war schon immer ein Grundinteresse vorhanden. Dieses hat sich weiterentwickelt, auch durch die Anforderung, der Gesellschaft und der Unternehmensleitung. Das führte dazu, dass sich eine Projektgruppe formiert hat. Die vor kurzem in ihrer Zusammensetzung auf die heutigen Anforderungen neu ausgerichtet wurde. Unabhängig hiervon beschäftigt sich diese Projektgruppe seit zehn Jahren aktiv sich mit diesen Themen.

Die Projektgruppe setzt sich aus Mitarbeitern zusammen die die Verantwortung für technischen Anlagen und Systeme wie z.B. Beleuchtungstechnik, Fahrtreppen, Aufzüge, Heizung, Klima, Lüftung tragen. Maßgeblich gehören, auch die Verantwortlichen für die U-Bahn-Fahrzeugtechnik als auch der Bustechnik dazu den hier liegt der höchste Energieverbrauch. Auch Bereiche die für Informationstechnologie verantwortlich sind werden, inzwischen eingebunden. Räume in welchen sich Informationstechnologie befindet (Rechenzentren) sind erhebliche Wärmelasten. Diese

Geräte haben einen hohen Strombedarf mit entsprechender Abwärme und müssen durch stromintensive Klimageräte gekühlt werden. Die Projektgruppe wird inzwischen ergänzt, auch durch Mitarbeiter aus dem Rechtsbereich. Das heißt also Juristerei und Steuerrecht wird bei dem Thema Energie auch immer komplexer. Auch Mitarbeiter aus dem Einkauf wirken in der Projektgruppe mit. Hierzu gehört im liberalisierten Energiemarkt auch der Stromeinkauf Auch die Rolle des Marketings und der Pressearbeit darf man dort nicht unterschätzen, die auch inzwischen in diese Gruppe dazugestoßen sind, weil die sicherlich wichtig ist die guten Dinge die dort in der Projektgruppe erarbeitet werden auch zu kommunizieren. Hatten wir vorhin besprochen, wie kommunizieren wir, eine ganz, ganz wichtige Aufgabe. Die Hochbahn hat sich, um auf das eigentliche Thema Energiemanagement noch ein bisschen konkreter einzugehen, in 2014 erstmalig die Frage gestellt, ob man ein Energiemanagement nach den ISO einführt oder ob man den Weg des Energieaudits wählt. Wir hatten uns dann dafür entschieden, nicht das Energiemanagement zu nehmen, sondern das Energieaudit, weil wir die Einschätzung hatten, dass wir mehr Freiheiten und eigenen Gestaltungsraum bei dem Energieaudit haben und uns nicht sklavisch an einer DIN abarbeiten müssen. Deswegen war die Einschätzung mehr Freiheiten zu haben, in dem eigenen Handeln die Grundlage unsere Entscheidung. Was nun in der Tat für ein Unternehmen besser oder schlechter ist, fällt mir fast schwer zu sagen, aber ich glaube wir beschäftigen uns, unabhängig davon, dass wir „nur“ das Audit machen, welches sich im Übrigen in vielen Punkten dicht an der DIN anlehnt, sehr intensiv mit diesem Thema. Der Vorstand ist eingebunden in die regelmäßige Berichtserstattung und gibt auch gegebenenfalls Hinweise und macht Vorgaben. Also unabhängig von dem Verfahren welches wir gewählt haben ist aus meiner Sicht für unser Unternehmen das Energieaudit ein guter und sinnvoller Weg. #00:15:28#

I: Ja, also das ist schon ein sehr umfangreiches, mehr als ein Projekt, sondern eine ganze Bewegung, die ja seit einigen Jahren läuft. Ich frage, mich wie man auch noch heute Potentiale im Unternehmen findet? Findet dann diese Arbeitsgruppe alle diese Ideen oder woher kommen dann die Ideen und wie werden sie bewertet? #00:15:54#

B: Ja, das ist nur ein Kanal die Arbeitsgruppe. Also es gibt da eine Vielzahl von Kanälen. Einige spreche ich gerne an. Weitere Kanäle sind, das Verbesserungsvorschlagswesen im Unternehmen. Auch dort kommen Kolleginnen und Kollegen zum Zuge, die nicht tagtäglich mit diesen Themen beschäftigt sind, die vielleicht auch mal querdenken, auch mal andere Ideen haben als die Fachfrau oder der Fachmann und deswegen ist diese kritische sehr wichtig. Auch wenn Verbesserungsvorschläge dabei sind wo die Fachfrau der Fachmann drüber schmunzelt, wenn von zehn oder zwanzig Vorschlägen einer wirklich ein Topvorschlag ist, hat das System schon seinen Nutzen erreicht. Das heißt also, ist das Vorschlagswesen sehr wohl ein Kanal, den wir nutzen und über diesen kam zum Beispiel die vorhin erwähnte Änderung der Nachlaufzeit von Fahrtreppen in Blickfeld: „Ist die Nachlaufzeit unserer Fahrtreppen eigentlich zu lang?“. Es gibt

Fahrtreppen, die sich erst einschalten, wenn jemand diese „betritt“ und schalten sich wieder nach einer bestimmten Zeit ab sofern sich keine Personen mehr auf der Fahrtreppe befindet. Diese Nachlaufzeit haben wir uns aufgrund eines Vorschlages angesehen und von ca. dreißig Sekunden auf ca. fünfzehn Sekunden reduziert. Der Fachmann oder die Fachfrau hatte sich darüber schon gar keine Gedanken mehr gemacht. Also insofern, eine wichtige Eingangsquelle. Eine weitere wichtige Eingangsquelle ist natürlich auch, dass man im Rahmen von Projekten prüft: Ob es angefangen von der Bautechnik bis zu technischen Anlagen und Systemen Neuerungen gibt die sinnvoll zu berücksichtigen sind. Das heißt also, nicht nur immer auf sein Bestandssystem und seine Bestandstechnologien schaut und dieses unverändert übernimmt. Sondern prüft: Was gibt es vielleicht in dem Umfeld an neuen, sinnvollen Dingen, die man auch mal bereit sein muss auszuprobieren. Das heißt also, man muss auch den Markt beobachten. Insbesondere wenn neue Projekte oder Anlageerneuerungen anstehen, ist es noch wichtiger mit diesen Dingen zu beschäftigen. Man darf, wenn die Wirtschaftlichkeit nicht das oberste Maß der Dinge ist, auch mal etwas Neues erproben. Das heißt also auch mal Technologien auszuprobieren, die auf den ersten Blick vielversprechend sind, aber noch gar nicht ausgereift sind. #00:18:53#

I: Also so Pilotanlagen sprichst du jetzt an, oder? #00:18:55#

B: Genau, dass man auch mal eine Pilotanlage zum Beispiel ausprobiert, in der Hoffnung, dass das Effizienzpotential, das man vielleicht bei Abschätzungen erstmal glaubt zu erreichen auch erreicht. #00:19:27#

I: Ja, verstehe. Kannst du vielleicht noch erzählen welches energierelevante Projekt dich in letzter Zeit so beschäftigt hat? Also du hast jetzt die Fahrtreppen erwähnt, vielleicht gibt es noch andere Beispiele? #00:19:46#

B: Also ja, mach ich gerne. Also, wir haben im Moment gerade sehr aktuell, Mitte März, ein neues Energierückspeisesystem in Betrieb genommen. Ein sogenanntes Hesop-System das ist ein System, welches die Bremsenergie der U-Bahn-Fahrzeuge, die mit „Gleichspannung“ betrieben werden und rückspeisefähig sind, wieder wechselrichtet, und dann unseren Wechselspannungsstromnetz zur Verfügung stellt. Das ist ein Projekt welches uns noch sehr beschäftigt, weil das System gerade in Betrieb genommen wurde und wir im aktuell prüfen ob die Ergebnisse so sind wie wir sie uns vorgestellt haben. Da dieses im Moment noch nicht der Fall ist, sind wir da noch am Nachsteuern. Das beschäftigt mich schon, es ist zurzeit nicht eindeutig zu erkennen, ob es z.B. an den geringeren Fahrgastzahlen, die wir durch Corona haben liegt. Also das ist ein Thema was uns aktuell beschäftigt. Es ist auch eine Aufgabe sich mit dem Thema Leuchtmittel, also Umstieg auf LED-Technik zu befassen. Hierzu gehört eine Pilotanlage im Bereich der LED-Beleuchtungstechnik, welche wir im letzten Jahr in Betrieb genommen haben. Bei dieser Anlage wird nicht nur tageszeitabhängig gesteuert, sondern auch über Präsenzmelder,

festgestellt ob sich Fahrgäste in der Haltestelle befinden oder in gewissen Abschnitten der Haltestelle und die Beleuchtungsstärke entsprechend angepasst. Also das ist ein spannendes Projekt, wir stellen sicher, dass selbst in dem Fall wo sich keiner in der Haltestelle befindet, die vorgeschriebene Beleuchtungsstärke nicht unterschritten wird. Wir haben auch ein weiteres sehr wichtiges Thema, das sprach ich vorhin an, die Umstellung des Bussystems auf E-Mobilität. Dort haben wir gerade die Situation, dass wir erste Schritte gehen und stellen fest, dass das Thema Abwärme der Ladetechnik, der Ladegeräte vertiefend zu betrachten. ist. Wie können wir diese Abwärme, gerade auf Busbetriebshöfen, wo sich auch Werkstätten sich befinden, nutzen. Das heißt also, z.B. als Heizenergie. Ein weiteres Thema, mit dem wir uns gerade heute Morgen befasst haben, auch im Bereich eines Busbetriebshofes, der die E-Busse vorbereitet wird, ist eine weitere Photovoltaikanlage die wir im nächsten Jahr dort planen und realisieren werden. Also es ist sehr vielschichtig, wir beschäftigen uns auch im Moment mit dem Thema Wärme. Das heißt also Heizungsanlagen. Wir haben auch ältere Heizungsanlagen und Heizungssysteme im Einsatz und dort gibt es heute viel effizientere Anlagen. Insofern ist das auch ein Themenfeld, mit dem wir uns konkret beschäftigen, wie wir effizienter werden können. Wenn ich in diesem Zuge noch einmal, auf die Bewertung der Effizienzmaßnahmen komme. #00:23:32#

I: Ja, gerne. #00:23:33#

B: Denn es gibt's dort auch mehrere Eingangsgrößen. Es ist wie ich es bereits erwähnt hatte, wichtig auch mal Innovation zuzulassen und mutig zu sein und auch das Risiko einzugehen, dass nicht alles eine Erfolgsstory wird. Wenn dort die Bereitschaft bis zur Unternehmensleitung besteht, etwas zu erproben, ist das immer sehr angenehm.

Unabhängig hiervon ist es für mich ein Maß, dass man auch mit einer neuen Technologie möglichst innerhalb einer Dekade eine sogenannte schwarze Null hinbekommt. Also man sollte schon im Vorweg eine Grobberechnung mit allen Facetten durchführen. Und wenn hierbei das Ergebnis ist, dass sich die Maßnahme in einer Dekade rechnet muss man dieses Risiko auch tragen. Was aber auch immer nach meiner Einschätzung wichtig ist, dass man bei der Betrachtung der Maßnahme und ihrer Kommunikation ehrlich ist Und deswegen wie gesagt diese Abschätzung und der Hinweis auf die Dekade. Bei einer wirtschaftlichen Betrachtung halte ich es auch immer für wichtig diese ganzheitlich durchzuführen. Das heißt also, sich nicht nur die Investition anzuschauen. Das wird ja immer gerne gemacht, dass man nur die erste Investition im Blickfeld hat, aber sich gar nicht damit auseinandersetzt was bedeutet die Maßnahme eigentlich für den Betrieb bzw. welche Betriebskosten sind zu berücksichtigen. Auch dieses gehört zu einer ehrlichen Betrachtung dazu. Da ist zum Beispiel das Thema Betriebskosten in einem U-Bahnsystem, wo wir die BOStrab (Verordnung über den Bau- und Betreib von Straßenbahnen) gilt und die hiermit verbundenen Vorgaben zu erhöhten Betriebskosten führen können. Dagegen bei einer Umsetzung in Verwaltungsbereichen oder im Busbereich dieses nicht der Fall wäre. Aber, für mich wichtig, ist die ganzheitliche Betrachtung damit hinterherkeine

Enttäuschung bei Controllern oder bei Unternehmensführung entsteht. Bei Grenzfällen darf man, wenn die Wirtschaftlichkeit eben nicht in einer Dekade gegeben ist, Projekte auch mal umsetzten, wenn alle wissen was sie tun und des Potentials dieser Technologie hoch einschätzt wird oder auch das Thema Nachhaltigkeit und Umweltwirkung höher bewertet werden kann als der rein wirtschaftliche Nutzten. Also insofern glaube ich auch dort darf man nicht nur schwarz oder weiß sehen, sondern muss dort eben auch die Farben dazwischen. #00:26:27#

I: Ja, sehr umfassend, also keine einfachen Entscheidungen. Als nächstes Thema würde mich interessieren auch das Monitoring, einerseits der Maßnahmenumsetzung und andererseits der Entwicklung des Verbrauchs im Unternehmen. Mich würde auch interessieren wie häufig diese Zahlen dann auch berichtet werden, ob das jetzt nur jährlich ist oder auch unterjährig und welche Kennzahlen da besonders wichtig sind. #00:27:09#

B: Also da muss man ein bisschen differenzieren. Da würde ich jetzt so beschreiben da ist bei uns noch mit Ausnahme von Strom und Diesel beim Monitoring noch Potenzial zur Detaillierung besteht. Es ist bei dem Monitoring so, dass mindestens unternehmensübergreifend, das heißt in Richtung Geschäftsführung, oder auch der Unternehmensbericht, der angesprochen worden ist, jährlich reportet wird. Das ist aber nur die aggregierte Ebene dargestellt. Das heißt also, im Rahmen des Energieaudits haben wir ganz, ganz viele Verbrauchswerte, die wir sammeln, bzw. gesammelt haben und auch bewertet haben. Das fängt an beim Strom, Diesel, das geht z.B. weiter bei Gas und Fernwärme. Bis zu der Betrachtung welchen Energieeinsatz muss ich eigentlich bringen, um Druckluft zu produzieren? Aber das alles wird aggregiert, jährlich zusammengefasst und dann auch an die Unternehmensleitung berichtet. Unterjährig ist es mehrschichtig. Mehrschichtig heißt, dass in der angesprochenen Projektgruppe Energieoptimierung auch auf Einzelmaßnahmen geschaut wird. In der Gruppe wird sehr genau begleitet welche Ziele bei den verschiedenen Projekten oder Themen erreicht oder auch nicht erreicht werden. Diese Ergebnisse werden innerhalb der Projektgruppe diskutiert. Darunter gelagert ist es so, dass die eigentlichen Fachkollegen, also der Kollege, der vielleicht die Beleuchtungsanlage optimiert hat, noch in kleineren Zyklen bewertet welchen Erfolg seine Maßnahme hat. Dieses gilt gleichermaßen für den Kollegen der eine neue Heizungsanlage installiert hat oder unser neues Rückspeisesystem. Bei dem neuen Rückspeisesystem wird zurzeit, täglich geprüft wie die Energiewerte sind. Bei anderen Anlagen geschieht dieses wöchentlich oder monatlich. Also das heißt, je dichter man an der Technologie dran ist, je präziser wird's auch gemonitort, aber es ist wichtig damit das nicht im Verborgenen bei der Fachfrau, bei dem Fachmann bleibt, auch von Unternehmensseite, bei uns eben das Modell dieser Projektgruppe aktiv nachzufragen, da sonst nicht auszuschließen ist das die Fachkollegen ihr Wissen für sich behalten. Also deswegen ist eine übergeordnete Stelle welche nachfragt oder an die regelmäßig zu reporten ist wichtig. #00:30:05#

I: Wenn ich dich jetzt fragen würde: Was hat die Hochbahn im März 2020 an Strom verbraucht? Würdest du das irgendwo gleich rausfinden können? #00:30:21#

B: Ja, also beim Strom könnte ich in der Tat in eine Datenbank gehen und dort könnte ich für jede Liegenschaft, jeden Busbetriebshof als Beispiel oder auch jedes Verwaltungsgebäude, eine exakte Aussage treffen … #00:30:38#

I: Und Unterwerk? Für jedes Unterwerk auch? #00:30:39#

B: Für jedes Unterwerk und jeden Mittelspannungsanschluss könnte ich sogar jeden Fünfzehn-Minuten-Wert sofort ermitteln. #00:30:46#

I: Aber nicht pro Platzkilometer gleich? Eine Summe pro Platzkilometer oder eine Kennzahl hättest du nicht für mich für März? #00:30:53#

B: Die hätte ich nicht online und müsste manuell errechnet werden. Anders sieht das aus bei Wärmeverbräuchern, beim Wärmeverbrauch. Da sind wir nicht so schnell, weil die Zähler noch nicht online angebunden sind. Aber bei dem Strom sind wir auf der Mittelspannungsebene weit. Wenn ich jetzt auf die 400 Volt Ebene gehe, sind die Werte nicht so schnell verfügbar. Wenn wir auf das Thema Kennzahlen auch ein bisschen genauer eingehen wollen, dann gilt für die Hochbahn dort in der Aggregationsebene, ist eine wichtige Kennzahl der spezifische Energieverbrauch. Der Stromverbrauch pro Kilowattstunden pro Nutzplatzkilometer fürs System U-Bahn, wird schon über Jahrzehnte immer verfolgt und sinkt zum Glück im Moment weiterhin. Da steht für mich im Moment die spannende Frage an wie sich dieser Wert. Durch die zunehmende Klimatechnik in den U-Bahn-Fahrzeugen entwickeln wird. Genauso wird der Kraftstoffverbrauch für die Busse auch Liter pro Nutzplatzkilometer betrachtet. Es gilt gleichermaßen für das Thema CO2-Emission. Das Ganze ist die oberste Aggregationsebene, darunter betrachtet können wir und tun wir dieses auch detaillierter für die einzelnen Systeme. Aber, bei unseren Verbrauchsmengen, ist der absolute Fokus sowohl der Kosten, des Energieverbrauchs und damit auch des Umweltnutzens auf dem Stromverbrauch der U-Bahnen und dem Diesel Verbrauch der Busse. Deswegen sind das die Schlüsselkennzahlen, auf die wir uns fokussiert haben. Aber in unseren Bestrebungen in Richtung 2030 volle Klimaneutralität zu erreichen, rückt im Moment auch solche Themen (wie Heizung, Klimatisierung und Abwärme) in das Blickfeld, also wir haben Fernwärme, wir haben Gas, wir haben Heizöl im System, die prozentual gesehen in Bezug auf Schadstoffe wie CO2, im Vergleich zum Diesel völlig untergeordnet sind. Aber wenn wir klimaneutral werden möchten, müssen wir uns diese Dinge auch ansehen und wenn wir kein Verkehrsunternehmen wären oder ein Unternehmen wären, welches nicht so viel Strom oder so viel Kraftstoff verbraucht, hätten diese Themen vermutlich eine ganz andere Wertigkeit. Diese wären auf einmal stärker im Fokus und deswegen ist es bei uns gerade so, dass wir uns sehr intensiv auch mit diesen Themen beschäftigen und Kennzahlen bilden wollen.

I: Du hast das Thema jetzt schon gerade angeschnitten, die Nutzung von erneuerbarer Energie. Also ich habe vernommen, dass ihr jetzt eine PV-Anlage am Dach auch errichten wollt bei einem Busdepot und gibt's vielleicht auch andere Projekte? Also gerade Richtung Erdwärme oder ähnliches? #00:34:41#

B: Ja also bei dem Thema erneuerbare Energien sind wir auch, auf leisen Sohlen schon seit vielen Jahren unterwegs. Aber dort bin ich mir sicher, wird Zukunft noch mehr kommen. Wir haben Photovoltaiktechnik im Einsatz, auf einem Busbetriebshof. Wir haben mehrere, also mehrere hört sich zu groß an, zwei Solarthermieanlagen im Einsatz. Wir haben auch ein Blockheizkraftwerk im Betrieb. Wir haben das Rückspeisesystem, welches ich erwähnt hatte. Wir haben zwei Schwungmassespeicher, das sind im U-Bahnsystem auch Rückspeise- /Speichersysteme, die Bremsenergie der U-Bahnen in kinetischer Energie zwischenspeichern und dann wieder den U-Bahnen als Fahrstrom zur Verfügung stellen. Das heißt, wir haben einiges bereits umgesetzt. Es gibt in Hamburg ein neues Klimaschutzgesetz, das noch mehr Dynamik, in den nächsten Jahren zur Folge haben wird. Wir werden ab 2023 verpflichtet bei Neubauprojekten noch mehr auf das Thema erneuerbare Energien einzugehen. Es gibt heute ja schon Vorgaben, wieviel Prozent der benötigten Energie bei Neubauten aus erneuerbaren Energien stammen muss. Die grundsätzlichen Anforderungen werden weiter gesteigert. Es gibt Hinweise, zur Verpflichtung von Photovoltaikanlagen bei Neubauten ab 2023. Ab 2025 wird es vermutlich auch Bestandsanlagen betreffen, wenn man dort wesentliche Veränderungen durchführt. Das heißt also, es gibt neben dem eigenen Anspruch Gutes zu tun für die Umwelt auch Rahmenvorgaben. Wir sind vielleicht jetzt mit einer Entscheidung, die wir heute Morgen getroffen haben, dass wir eine weitere Photovoltaikanlage auf einem Busdepot installieren werden, ein bisschen vorlaufend, bezogen auf die kommende Verpflichtung. Aber das entspricht ja auch dem was ich am Anfang gesagt hatte, dass wir auch einen entsprechenden Anspruch haben. Das System U-Bahn ist durch gewisse Anforderungen des Gleichstroms manchmal aufwendiger/teurer Dinge oder Produkte nutzbar zu machen. Bei dem Thema Neuanlagen ist auch ein Thema mit dem wir uns immer wieder beschäftigt haben zum Beispiel beim Neubau derU4, die Nutzung von Erdwärme, also Geothermie, weiter in den Fokus zu bringen. Bisher konnte bei der U4 keine sinnvolle Umsetzung nachgewiesen werden dieses, mag vielleicht auch in den geologischen Hamburger Verhältnisse begründet sein. Dann sind wir wieder bei dem Thema Wirtschaftlichkeit Umwelt und der Gesamtbewertung die wir dort vorgenommen haben und somit es bisher nicht zu einer Umsetzung gekommen ist. Wir haben uns auch vor einigen Jahren mit dem Thema „Nutzung von Abwärme aus Tunnelanlagen", beschäftigt. Das Thema Photovoltaik hat sich in den letzten Jahren nach meiner Einschätzung weiterentwickelt und ist inzwischen auch ein etabliertes Thema, hier besteht durchaus bei uns auch noch Potenzial#00:38:27#

I: Das ist natürlich erfreulich, dass man auch noch Ideen für die Zukunft hat und dort vielleicht auch neue Potentiale noch erschließen kann. Eine weitere Frage wäre zum Thema

Strombeschaffung oder Energiemix, der beschafft wird. Wie du schon erwähnt hast ist der Strom die Hauptenergiequelle bei euch und deswegen geh ich davon auch aus, dass dort auch sehr viel Stellenwert beigemessen wird. #00:38:59#

B: Ja, da haben wir uns über die Jahre auch weiterentwickelt. Es hat sich das Thema Strom, Stromeinkauf in den letzten rund fünfzehn Jahren deutlich verändert. Es gab früher die Rundum-sorglos-Pakete, man hat seinem Stromversorger einen Auftrag gegeben und hat dann das bekommen, was er einem so angeboten hat. Durch den liberalisierten Strommarkt, das heißt: Trennung Netz- und eben auch Energielieferung, haben die Unternehmen und damit auch die Hochbahn, angefangen sich generell mit dem Thema mehr zu befassen. Man hat dann auch auf Grundlage der steigenden Umweltnachfragen von Dritten, beziehungsweise auch der eigenen Sensibilisierung angefangen sich mehr damit zu beschäftigen: welche Qualität, im Sinne der Produktion und Umweltbelastung, hat eigentlich mein Strom? Wie vielen Unternehmen wie auch uns wurde bewusst, dass man eigentlich den Energiemix bekommt, den letztendlich der eigene Stromversorger in das Netz einspeist. Das heißt also, mit Gas als primär Energieträger war man schon gut bedient gewesen, aber es ist auch viel Kohle dabei gewesen oder auch Atomstrom, der sicherlich in Richtung CO2 unproblematisch ist, aber andere Probleme mit sich bringt. Und das heißt also wir haben vor sehr vielen Jahren angefangen uns mit der Stromqualität zu beschäftigen und Vorgaben in unsere Ausschreibungen aufgenommen. Inzwischen sind die Vorgaben sehr präzise, es muss Strom sein, der hundert Prozent erneuerbaren Energien zuzuordnen ist und nicht nur einfach „zuzuordnen“ ist und muss auch in das europäische Stromnetzt eingespeist werden. Das ist ein Punkt, der Strom muss auch über Herkunftsnachweisregister zugeordnet werden. Das bedeutet es muss, auch nachvollzogen werden können aus welchem Kraftwerk oder aus welcher Anlage der Strom kommt und eine Doppelvermarktung zu vermieden. Und damit wir auch wirklich den Gedanken einer kontinuierlich verbesserten Qualität der Stromlieferung weiterverfolgen, haben wir auch eine Vorgabe getätigt was das Alter der Anlagen angeht. Wir hatten uns dazu auch viele Gedanken gemacht über die Jahre, da gabs auch Änderungen was die Altersstrukturen betraf, aber aktuell, seit letztem Jahr, ist es so, dass die Vorgabe ist, dass der Strom aus erneuerbaren Energieanlagen stammt, deren Anlagenalter nicht älter als sechs Jahre ist. Wir glauben hiermit den Impuls zu setzen, dass auch in neue Anlagen investiert wird. Dieses Modell mit den sechs Jahren wird nicht ewig funktionieren. Davon wird man sich, wenn genug Umstellung im Markt stattgefunden hat, sicherlich verabschieden müssen. Aber wenn man was verändern will, dann ist es heute sinnvoll hier eine Vorgabe zumachen. #00:42:49#

I: Dankeschön auf jeden Fall. Also ich wäre mit meinen Fragestellungen soweit durch und der Abschluss wäre dann nur welches Thema vielleicht noch nicht besprochen wurde oder welches Thema dir vielleicht noch am Herzen liegt, wir können natürlich auch über die E-Bus Flotte noch

sprechen, die ja auch ein großes Thema ist oder sonst noch ein Thema was dir einfällt. #00:43:14#

B: Also ein Punkt der mir am Herzen liegt muss ich nennen, hab ich auch lange Jahre wahrscheinlich selber unterbewertet oder gar nicht wahrgenommen, ich habe versucht es auch in den anderen Fragen immer mal wieder ein bisschen durchblicken zu lassen, ist das Bewusstsein der Bevölkerung. Das heißt der Menschen inzwischen zum Thema Energie und Umwelt. Und dieses Bewusstsein ist gerade bei den jungen Leuten in der Wertigkeit ganz anders als das vielleicht in zurückliegenden Generationen der Fall war. Deswegen glaube ich, dass wir als ÖPNV-Unternehmen gut beraten sind dieses eben auch zu vermarkten, dieses aber auch im Rahmen der Personalgewinnung und Recruitings zu nutzen, weil viele junge Leute sich dann noch besser mit dem Produkt, ÖPNV, identifizieren können, wenn ihnen auch nochmal deutlich wird was sie Gutes tun. Und, dass es nicht nur Gut ist mit uns zu fahren, sondern, dass wir uns auch darüber Gedanken machen neue Technologien mit zu unterstützen, voranzutreiben sie effizient und umweltgerecht zu machen. Das ist wichtig, in dem Wettbewerb um Fachkräfte, für sich, als Benefit mit zu nutzen. Deswegen ist das inzwischen, hätte ich vor zehn Jahren auch nicht behauptet, ein persönliches Anliegen von mir, dieses auch in Bewerbungsgesprächen und auch Bewerbungsverfahren zu nutzten. Zweites Thema, das ist das angesprochene E-Bus-Thema. Es ist aus der Fachlichkeit heraus klar, dass es notwendig und sinnvoll ist diese Umstellung voranzubringen und voranzutreiben, aber man sieht eben auch, ich sprach vorhin das Thema Abwärme an es gibt Themenfelder die zu bearbeiten sind. Für die Umwelt ist es bei dieser Umstellung wichtig Strom aus erneuerbaren Energien zu nutzten und damit wegkommt von den fossilen Kraftstoffen und hiermit das Thema CO2 und letztendlich Schadstoffe, Abgase minimiert.

Bei der Einführung von neuen Systemen, neuen Technologien sollte auch immer kritisch geprüft werden, ob wirklich schon alle Potenziale gehoben wurden. Das wäre vielleicht auch noch so ein Punkt, eine Botschaft, die ich gerne nochmal loswerden möchte. #00:45:59#

I: Also immer nach Verbesserungen suchen, ja? #00:46:01#

B: Ja, das sollte jetzt gerade beim Thema Energieeffizienz ein Anspruch sein, ja. #00:46:09#

I: Ja, dann denk ich mir ist das ein schöner Abschluss für unser Interview. Haben wir soweit alle Themen angesprochen, passt das für dich soweit? #00:46:21#

B: Also ich glaube, dass ich alles das untergebracht habe was mitteilen wollte. Das einzige was ich vielleicht nochmal, erwähnen möchte weil ich es ja eigentlich ganz nett finde als Unternehmen, es heißt so schön auch in den Unternehmenswerten der Hochbahn, das hab ich vielleicht unterschlagen: „Die Hochbahn übernimmt Verantwortung, gesellschaftliche Verantwortung zu unternehmen, bedeutet für uns also als Hochbahn allen Hamburgerinnen und Hamburgern Mobilität zu ermöglichen, mit uns lebt die Stadt und dank des aktiven Umwelt- und Klimaschutz treiben wir sie voran“. Das ist find ich ist ein Leitspruch den wir gerade in der Kommunikation

auch für die Mitarbeiter, einsetzten und in unserem Mitarbeiterportal auch eingesetzt wird. Aber ansonsten glaub ich habe ich alles das was ich kommunizieren wollte kommuniziert. #00:47:20#

I: Dann sag ich herzlichen Dank Frank. Es war sehr ausgiebig, ich schau jetzt meine Notizen gerade durch und werde sie alle noch detailliert durchgehen und ja, ich bedanke mich an dieser Stelle sehr herzlich für dein Interview und für deinen Bereitschaft mich bei meiner Masterarbeit zu unterstützen und ich hoffe, dass die Corona Krise soweit sobald vorbei ist, dass wir auch mal nach Hamburg kommen können und uns die Neuerungen und Verbesserungen auch alle ansehen können. #00:47:50#

B: Sehr gerne seid ihr herzlich eingeladen. Auf der anderen Seite schauen wir uns natürlich gleichermaßen in Wien oder auch an anderen Orten natürlich auch gerne die Verbesserungen an, denn wir können da alle nur voneinander profitieren. Abschließend wünsche ich Dir viel Erfolg für die Masterarbeit und wenn da noch Nach- und Rückfragen bestehen, weil ich vielleicht ein bisschen zu schnell war, zu unpräzise, ist das gar kein Problem. #00:48:19#

I: Dankeschön #00:48:25#

Interview questionnaire for Master Thesis "SUSTAINABLE ENERGY POLICIES FOR PUBLIC TRANSPORT UTILITIES" by Eva Keuschnig, WU Executive Academy, MBA

Answered by Mr. Ignasi Oliver Gonzalez from TMB, FC Metropolità de Barcelona, Director de Sistemes de Circulació de la Xarxa (Director of the Network Circulation Systems)

Biography: Ignasi Oliver Gonzalez joined TMB in 1988 in Metro de Barcelona as engineer of remote-control Systems department. After that he has been manager of several departments of maintenance and projects, signaling, telecommunication communications, energy and electromechanical installations. Nowadays he is the Director of Transit Service, of Maintenance and Projects Area, leading +200 people. He has been involved in the major changes in the metro network, introducing automation, adapting installations, procedures and organizational charts to the needs of the metro operation, driverless lines saving operational, maintenance and energy costs. His main focus has been to provide the best availability to get the best metro service with limited costs. Now he is leading the change of processes and culture to get a true transformation by mean of the digitalization.

Date: May 02, 2020

Pillar 1 Energy Policy

Is there an energy policy in your company? How important is it?

Yes, there is an energy policy. The energy policy is very important because the consumption of energy in my company is huge. We are the main public transport operator in Barcelona with a fleet than more than 1.150 buses and 160 trains. Out energy consumption is approximately 275 GWh of electricity and 30 million liters of fossil fuels a year. Energy costs are as high as 50 Mill EUR, which is the second largest cost budget position, after labor costs. Awareness for savings and efficiency is very high at our company. Our goal is to:

- to improve in terms of productivity and competitiveness,
- to contribute to the reduction of gas emission pollutants and to reduce CO2 to support climate change

How is it communicated internally and externally?

Internally; The company realizes that implementing an energy management system and achieving our energy goals depend on the commitment of all levels and functions of the organization. We understand that communication is essential. The communication is supported by using corporative channels, intranet, Gent TMB App by mean of regular bulletins with reports

and videos: TMB News & TMB people. Additionally, meetings and training courses are done for specific staff involved in some aspect related to energy management.

Externally: Via TMB web, we provide general information about the company and our energy policy. There one can find several publications related to energy, like the general plan of environmental sustainability, energy policy, sustainability policy, environmentally responsible purchase policy, and others.

Also, by registering to JoTMBé web and App there we offer access to TMB News bulletin and other information and we provide additional information via TMB Foundation web. TMB Foundation also organizes exhibitions, conferences and visits, sometimes related on energy. Adds are communicated via social networks like LinkedIn, Tweeter, Instagram

Are the stakeholders interested?

Stakeholders are public authorities and the city government which are interested in our contribution to achieve energy cost reductions and reduce pollution, supported by an energy management system.

Due to the periodic surveys of Barcelona City Council, 89% of the citizens of Barcelona are concerned about climate change. Therefore, we know that our passengers are also interested in an environmentally friendly transportation service. From internal surveys we have learned that more than 80% of users think that TMB is making efforts to improve the quality of the environment.

Pillar 3 Energy Management

How is the energy management structured in the company? Who is involved? What does the team look like?

It is a multidisciplinary team. The team is made up of people from the departments of environment, energy maintenance, energy projects, finance, procurement and legal advice.

They have regular meetings to follow KPIs and projects in progress and are involved in planning projects. The frequency of the meetings depends on the number of ongoing projects, and those to be planned for next year, whether there is an upcoming audit and so on.

How is the potential for improving energy efficiency determined?

We did an initial audit over energy consumptions and costs in 2016. Two kind of improvements were determined:

- Energy reduction (energy savings) and
- Power adjustment (same energy but cost reduction due to adaptation to regulation changes)

After that we identified all the potential areas of improvement, undertaking a cost / benefit analysis for each one, based on technical information or benchmarking (i.e. UITP, Nova, Comet).

The projects and investments were prioritized according to a cost/ benefit relation. We chose the most suitable technology in each case, preferably tested technologies. The targets are defined in projects and are used to write the procurement specifications. Once the project is in operation, metering and data analysis is done to checks if targets are met.

What criteria are used to measure energy efficiency measures?

We compare energy targets with energy achievements. Once the project is operating, we check, if the targeted % of energy savings is achieved.

Which energy-relevant project have you been dealing with recently?

Efficient ATO driving mode in, L2 & L5 (finished)

Installation of IGBT's Traction Inverters for braking energy recovery to be used in stations facilities.

Replacement of fluorescence tubes by LED tubes in stations, tunnels & Depots

Adjustment of Power to current necessities (saving cost by adaptation to regulation changes)

More efficiently regulation of HVAC on trains

Increasing individual energy meters and introducing an overall monitoring system

Electric vans fleet for maintenance departments, installation of chargers

Test electrification of bus depots for electrical buses. Quick chargers in final stops of some bus lines

Implementation of widgets in the digital train tool to check in real time and historic register of the different consumptions of trains for every train at each point of the line.

Study for use of hydrogen bus

What specific energy related project do you plan to implement in the near future?

Efficient ATO driving mode in, L2 & L5 (finished), L1 & L3 planned

We continue with the replacement of fluorescence tubes by LED tubes in stations, tunnels & Depots

Installation solar panels in a car park site this year to get energy for electric cars

Implementation of a global energy management system (ISO 50.001)

Energy recovery inverters in 100% TMB-Metro lines (10-12 inverters)

More electric buses and chargers in depots and at the ends of some lines

Trial on use of hydrogen buses

How does the monitoring of energy efficiency measures work?

The monitoring systems work well. But as we have progressed with audits and improvement measures, we had to increase the number of meters in order to identify with more detail the services that could be improved.

Which KPIs are reported periodically? To whom?

Several KPIs related to service quality and sustainability are reported periodically, both for metro and bus. Target and yearly achieved value. Energy consumption (KWh), emissions: CO2 ns (Tn) NO (Kg), PM (gr).

Also estimated saving of CO2, NO and PM emissions generated with the transport of passengers comparing with the generated by private vehicles in relations to passenger transport.

Yearly energy real consumption and objective value in kWh. This data is available in both; the intranet and internet

We work with absolute kwh, monthly and later we were analyzing for each energy service. The first division was between stations and trains. We noticed that trains consumed 72 % of total energy consumption and stations 28 % This showed that we had more room for improvement in train consumption. Measuring in detail trains showed that mechanical effort is the main consumption 77 %, more than 32% of the global traction energy is provided by regenerative braking, but approx. 12 % is still lost in breaking resistors. That is why we decided to priories the energy recovery invertors project. HVAC and lighting in trains is 21%

Also looking deep in stations consumption, ventilation 38 % and lighting 33 % are the main consumers, and then escalators 11 %, shops 8 %, lifts 5 %, air conditioning 3 % and pumping 2 %.

Some monthly KPIs for internal use:

For high voltage supply:

Active Energy (kWh)

Reactive Energy (kVArh)

Energy in kWh in TMB transformer bars.

Energy in MWh in supplier central bars.

Energy in MWh lost in networks.

Daily electricity consumption in MWh.

Daily capacity of electricity consumption in unused MW

Daily utilization ratio of the contracted power in%.

Daily non-use ratio of the contracted power in%.

For every Metro Line:

Monthly electrical energy consumption in traction and non-traction services.

Primary units of energy in kg of oil equivalent (kgoe) per kilometer traveled.

Primary energy units in kg of oil equivalent (kgoe) per passenger.

High voltage consumptions in kWh

Low voltage consumptions in kWh

Natural gas consumptions in kWh (in workshops)

For trains circulations, amounts recorded in daily service as follows.

Energy absorbed by the train (kWh).

Energy transferred to the catenary (kWh).

Energy consumed in braking. (kWh).

Energy consumed by auxiliary train services (kWh).

Pillar 3 Renewable Energy

Do you use renewable energies on site? Which sources are you already using? Are there any expansion plans?

Not yet. We are installing solar panels in a car park site this year. We have studied other possible locations: Garage or workshop roofs and also stations roof or sections of track in viaduct section of Line 10. The decision will be taken after testing the results of the park site done this year

No heat recovery or geothermal energy use yet.

What electricity mix are you currently using? How do you get the energy?

Energy supplied is green certified. The electricity supply for conventional lines (L1,2,3,4,5, & 11) is contracted in a public tender directly from TMB. We do a join tender with other four cities: Bilbao and Málaga metros, Murcia and Zaragoza trams. Last tender was for 2 years in 2020.

Merging our procurement efforts lead to an increase of the procurement volume up to 350 GWh gave us some pricing power and resulted in better prices for cities joining to this procurement tender. As much important is the contract more attractive is for the supplier and better prices you can get. We have the biggest part (approx. 70 %) but increasing the kWh in tender we assume we get better prices

In automatic lines it is different because there are new lines owned by Ifercat. Ifercat is a public body of the Catalonia Government focused on railway infrastructure (designing, building, conserving, managing and administering). Here TMB is only the operator who pays a usage fee a canon a fee for the use of the infrastructure, whereas the energy is provided by Ifercat.

Pillar 4 discussion

What else is important for you regarding this topic?

Mobility is a key factor for economy. Efficient and rapid public transport makes a better life of citizens. On the other hand, we need to “clean” the planet if we want it to remain as it is, with biodiversity, life compatible climate and healthy air. The energy we consume is key for this, additionally to the amount and origin of waste we produce.

Continued measurement of energy consumption remains important to identify areas of improving.

We are in the era with the most rapid changes ever. This also means there are many opportunities to improve. For me is a must to work to introduce all improvements available in energy efficiency. And do this with a wide point of view. For example, using hydrogen buses is not easy. Is a new technology that require adaptations in workshops, training of technical staff, which is expensive. But on the other hand, comparing to electrical buses, it avoids carrying tons of batteries that need charging during the day. Producing hydrogen have a lot of energy losses but if we increase the production of renewable energies is an opportunity to storage electricity without the wastes of batteries and use the residual green electricity produced in periods of low demand. Testing it in our companies can help to improve that technology.

Digitalization can also help in many ways, for example:

Adjusting the supply to the demand very precisely to avoid almost empty vehicles, or intervals that make public transport seem unattractive. For example, measuring occupancy of trains in real time allows schedules that are adjusted very precisely to the demand, and in driverless lines even in real time injecting more trains to the line when are required. We are using and algorithm for conversion the value of suspension pressure available in data network of the trains to load in kg to determine the occupancy of trains in real time. This and other data of the trains are available on OCC in real time.

Adjusting ventilation systems very precisely, with temperature and humidity sensors and synchronization with passing trains, that produce air currents that will regulate the speed and direction of the fans accordingly. We did a test in one line and it was possible to reduce the temperature of the tunnel by 0,5 degree containing the electricity consumption.

Automatic switching off part of lighting of stations at night where there are not works caused decrease of 10% in night consumption.

Driverless metro or GOA2 metro where there are no human inefficiency driving Also ECO driving modes can be introduced. We reduced 15 % traction consumption in L2 & L5. With a new program of efficient ATO, this could go further with digitalization if an accurate synchronizing of braking and starting trains. Driverless metro allows a lot of flexibility on the service introducing or retiring trains where the demand changes without the need of having drivers available.