Handbook of evaluation methodologies for electric bus systems

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SUMMARY SHEET

Programme	Seventh Framework Programme
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Project Title	Zero Emission Urban Bus System
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Coordinator	UITP – International Association of Public Transport
Project Director	Umberto Guida, *umberto.guida@uitp.org*
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Abstract	As a major result of the project, a common evaluation methodology supporting procurement for future investments in electric bus systems was delivered. This activity will combined the different methodological elements of procurement-oriented evaluation into a single handbook covering sustainability performance assessment, offering also support to feasibility and decision making, modelling and standardisation. The task also concentrated its effort in the preparation of a compendium of these activities and contributed to the communication of the most relevant aspects of procurement to the community, in line with the overall dissemination program.
Key words	
Thumbs Index	

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0.8	28/04/2018	Whole document	VTT	Final draft for comments
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8	D'APPOLONIA SPA	DAPP	Italy

ACRONYMS

DoW	Description of Work
HVAC	Heating, ventilation and air conditioning
IPT	Inductive Power Transfer
KPI	Key Performance Indicator
LCC	Life Cycle Cost
MCDA	Multi-criteria decision analysis
PT	Public Transport
PTA	Public Transport Authority
PTO	Public Transport Operator
RFP	Request for Proposal
TCO	Total Cost of Ownership
TOR	Terms of Reference

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1. EXECUTIVE SUMMARY

As a major result of the project, a common evaluation methodology for electric buses and bus systems, including the charging infrastructure to support procurement and future investments in electric bus systems was to be delivered. This report combines the different methodological elements of procurement-oriented evaluation into a single handbook covering sustainability performance assessment and offering support to feasibility studies and decision making, modelling and standardisation.

The task was also expected to concentrate its effort in the preparation of a compendium of these activities and contribute to the communication of the most relevant aspects of procurement to the community, in line with the overall dissemination programme.

Public entities are often seen as forerunners in adapting new, more sustainable and environmentally friendly practices and acquiring products with the same characteristics. As public acquisitions mostly include also a public and competitive tendering process, there is a need for clear and concise guidelines, how electric buses and electric bus transport services could and should be tendered.

European Union has issued a Directive (2009/33/EU on the promotion of clean and energy efficient road transport vehicles known as “Clean Vehicles Directive”. In its present format this Directive does not specifically contain any preference to electricity or any other fuel or energy, but is technologically neutral. It only states that energy and environmental impacts must be taken into account, and this assessment shall include at least energy (fuel) consumption, emissions of CO_2, NOx, NMHC and particulate matter (PM), and a uniform methodology for the calculation of operational lifetime costs shall be applied with predefined monetary values for each of the pollutants.

However, the Commission has introduced a proposal to amend this Directive (COM/ 2017/0653 final - 2017/0291 (COD), and that is being processed and discussed. In this proposal, electric drive has been given a clear preference, as according to the proposed definition of a “Clean Vehicle”, full-electric, hybrid-electric or fuel cell electric vehicles are specifically mentioned, together with bio-methane or natural gas. Furthermore, the proposal introduces also minimum procurement target volumes for clean vehicles or transport services by vehicles falling into the jurisdiction of this Directive.

Electric-driven buses differ from regular, ICE-powered busses at least in one fundamental way: eBuses need a supporting charging infrastructure that can supply the necessary electric energy, whereas regular ICE-busses can be catered with more traditional liquid fuel supply with similar qualities like the normal commercial road vehicle fuel infrastructure. Therefore, we should consider eBus and the charging infrastructure together as a system, and not treat eBus just like any other vehicle.

Furthermore, electric busses and the supporting charging infrastructure are both still emerging technologies with high-degree of technical diversity, but at the same time with only a limited number of suppliers. Lack of standards is at present also a token of the level of immatureness. Without proper standards, the market will not function in an open way, but can lead into a lock-in situation, where busses and the charging infrastructure cannot be decoupled in a sensible way due to lack of compatibility. This will be a serious hindrance also to an evolution of used vehicle market for eBuses, and thus complicate the assessment of depreciation.

In ZeEUS, each of the demonstrations had its own set of targets and objectives, and each demo was also evaluated as such by the demo team, aided by the scientific partner, usually an academic institution or a research organisation. In addition, a common evaluation was instituted, comprising all the demonstrations. This level of evaluation called "Global evaluation", and it was constituted by the Joint Evaluation Team (JET), comprising three partners: VTT, thinkstep and D'Appolonia. Furthermore, this team was supported by the scientific aides of the demos.

The Global Analysis in ZeEUS had multiple objectives:

- Propose and identify the most relevant KPIs for e-Buses and e-Bus systems
- Analyse the transferability of site-specific results
- Support feasibility studies and decision making, modelling and standardisation
- Compile a single handbook covering sustainability performance assessment from multiple viewing angles, and to
- Support procurement for future investments in electric bus systems

For the global evaluation in ZeEUS a five-step collaborative process was developed and executed. It was based on "Key Performance Indicator" concept, and constituted of:

1. Setting the bottom lines
2. Populating the KPI tree
3. System definition and selection of KPIs
4. Applying measurement plan with centralised data collection
5. Assessment form different point-of-view

For setting the base for the global-level evaluation of the ZeEUS demonstration activities, a **Triple Bottom-Line** (TBL) **concept was chosen**. Altogether, the process resulted in a quite comprehensive list of indicators: 185, of which 35 were for "People" bottom line, 53 for "Profit" bottom line, 26 for "Planet" bottom line, and 71 for Technical and Operational Data.

In the framework of ZeEUS, we have identified **four different main stakeholders that have different point-of-view to the process** of public transport services by buses with electric (or hybrid electric) propulsion.

These stakeholders are:

- City/Municipality
- Public transit authority (PTA), if exists in the framework
- Public transport operator (PTO), or equivalent actor in city/municipality
- Users

Each of these stakeholder types have their own set of targets and preferences and, thus they have **different priorities and most important core KPIs**.

While implementing an evaluation scheme and selecting KPIs, all these "voices" should be heard and catered equally, because public transportation is very much a joint effort, and no party should have an overruling position. In order to success in this endeavour, it is most **important to identify those indicators that are shared by most stakeholders**, as **those should be the real key indicators to be followed**.

Electric buses propose a lucrative option for future urban bus transport: zero emissions while driving, and full use of sustainable and renewable energy (low-carbon/carbon-free electricity). Apart from the environmental benefits, eBuses have many features that can make bus transport more appealing to the users.

However, electric buses are still in the early stages of their development, and especially the electric energy storage needs improvement in terms of cost and capacity. Furthermore, the infrastructure needed to supply and charge the electricity that the eBuses use, is another technology in development phase, even if public transport vehicles have been operating with electricity for over a century, but those (trams, metro, trolleys) have all been using direct and constant contact to the grid via catenary wires.

Electric buses and the charging infrastructure form a system rather than a product, and thus procurement of public transport services by electric buses is somewhat more complicated than procurement of bus services by regular ICE-driven buses. Especially challenging this becomes, when an opportunity-type of charging system is chosen, because then the charging hardware is to be placed in cityscape, outside the bus operators own premises (depot). Also the diversity of the technical solutions poses a challenge to make right choices, as the chosen architecture will lock the future development, as interoperability between systems is nearly nonexistent. Standardisation efforts have begun, and ZeEUS project has been an instrumental actor in advancing this work.

When using and selecting KPIs in procuring and contracting electric buses of bus services, one has to be very careful. To make right choices, one must understand the innards of a complex system and know "what drives what", because if a high-level KPI is used as metrics for service quality, one must always make sure that the sources, where the data is coming from and paths of information that is feeding this KPI are known, and the party in charge has the possibility to monitor also the root sources and make necessary adjustments, if necessary.

In other words: if any high-level output-type KPI is used to monitor the quality of the service, the operator must have control of the driver-type, operational KPIs. If there are more parties involved, it is important to choose the right KPIs to use as "tokens" for measuring/monitoring the propagation of value added in the process thru the chain of operations.

A good system definition and selection of right indicators should already be part of the TOR, as then the bidders could see, how their product or service is valued and how the value is monitored, and this should lead to a design of an effective product or .procedure. However, we must also remember, that the way something is measured and monitored, will always influence the process: "you get what you ask for". Therefore, the system definition and choice of indicators have a crucial role in the framework.

2. INTRODUCTION

2.1 Main objective

As a major result of the project, a common evaluation methodology for electric buses and bus systems, including the charging infrastructure to support procurement and future investments in electric bus systems was to be delivered. This report combines the different methodological elements of procurement-oriented evaluation into a single handbook covering sustainability performance assessment and offering support to feasibility studies and decision making, modelling and standardisation.

The task was also expected to concentrate its effort in the preparation of a compendium of these activities and contribute to the communication of the most relevant aspects of procurement to the community, in line with the overall dissemination programme.

2.2 The role of public procurement

Public entities are often seen as forerunners in adapting new, more sustainable and environmentally friendly practices and acquiring products with the same characteristics. As public acquisitions mostly include also a public and competitive tendering process, there is a need for clear and concise guidelines, how electric buses and electric bus transport services could and should be tendered.

2.3 Clean vehicles Directive

European Union has issued a Directive (2009/33/EU on the promotion of clean and energy efficient road transport vehicles known as “Clean Vehicles Directive”. In its present format this Directive does not specifically contain any preference to electricity or any other fuel or energy, but is technologically neutral. It only states that energy and environmental impacts must be taken into account, and this assessment shall include at least energy (fuel) consumption, emissions of CO_2, NOx, NMHC and particulate matter (PM), and a uniform methodology for the calculation of operational lifetime costs shall be applied with predefined monetary values for each of the pollutants.

However, the Commission has introduced a proposal to amend this Directive (COM/ 2017/0653 final - 2017/0291 (COD), and that is being processed and discussed. In this proposal, electric drive has been given a clear preference, as according to the proposed definition of a “Clean Vehicle”, full-electric, hybrid-electric or fuel cell electric vehicles are specifically mentioned, together with bio-methane or natural gas. Furthermore, the proposal introduces also minimum procurement target volumes for clean vehicles or transport services by vehicles falling into the jurisdiction of this Directive.

2.4 eBuses and supporting infrastructure

Electric-driven buses differ from regular, ICE-powered busses at least in one fundamental way: eBuses need a supporting charging infrastructure that can supply the necessary electric energy, whereas regular ICE-busses can be catered with more traditional liquid fuel supply with similar qualities like the normal commercial road vehicle fuel infrastructure. Therefore, we should consider eBus and the charging infrastructure together as a system, and not treat eBus just like any other vehicle.

Furthermore, electric busses and the supporting charging infrastructure are both still emerging technologies with high-degree of technical diversity, but at the same time with only a limited number of suppliers. Lack of standards is at present also a token of the level of immatureness. Without proper standards, the market will not function in an open way, but can lead into a lock-in situation, where busses and the charging infrastructure cannot be decoupled in a sensible way due to lack of compatibility. This will be a serious hindrance also to an evolution of used vehicle market for eBuses, and thus complicate the assessment of depreciation.

2.5 Schemes for public (bus) transport

Public transport (PT) can be arranged in many ways, and several schemes are implemented in European Member States. The traditional model has been that the municipality is producing the PT services, and the active operations are provided by an organisation (or organisations) belonging to the communal enterprises.

This approach is still widely used, but a more recent set-up is based on a public transport authority (PTA), who is in charge of the planning of the PT actions, but the actual operations are provided – on contractual basis – by one or several public transport operators (PTO) that are usually private enterprises. Perhaps the largest and most widely known implementation of this scheme is in London, where Transport for London (TfL) is the PTA, served by a number of different PTOs.

Both of these arrangements need different approaches regarding procurement and tendering, and pose different challenges to those parties involved. However, regardless of the framework, the process has many similar elements and functionalities.

3. EVALUATION METHODOLOGY IN ZEEUS

3.1 Evaluation schemes in ZeEUS

Each of the demonstration is ZeEUS had its own set of targets and objectives, and each demo was also evaluated as such by the demo team, aided by the scientific partner, usually an academic institution or a research organisation. In ZeEUS vocabulary this evaluation was also referred as “vertical evaluation”. In addition, a common “horizontal evaluation” was instituted, comprising all the demonstrations. This level of evaluation called “Global evaluation”, and it was constituted by the Joint Evaluation Team (JET), comprising three partners: VTT, thinkstep (formerly PE International) and D’Appolonia (now an integral part of RINA Consulting).

This team was supported by the scientific aides of the demos, often referred as ”Liaison Bodies” (LB), because they acted as the link between the demonstrations and JET.

3.2 Global evaluation in ZeEUS

The Global Analysis in ZeEUS had multiple objectives, such as:

- Propose and identify the most relevant KPIs for e-Buses and e-Bus systems
- Analyse the transferability of site-specific results
- Support feasibility studies and decision making, modelling and standardisation
- Compile a single handbook covering sustainability performance assessment from multiple viewing angles, and to
- Support procurement for future investments in electric bus systems

For the global evaluation in ZeEUS a five-step collaborative process was developed and executed. Figure 1 depicts the general concept of this process.

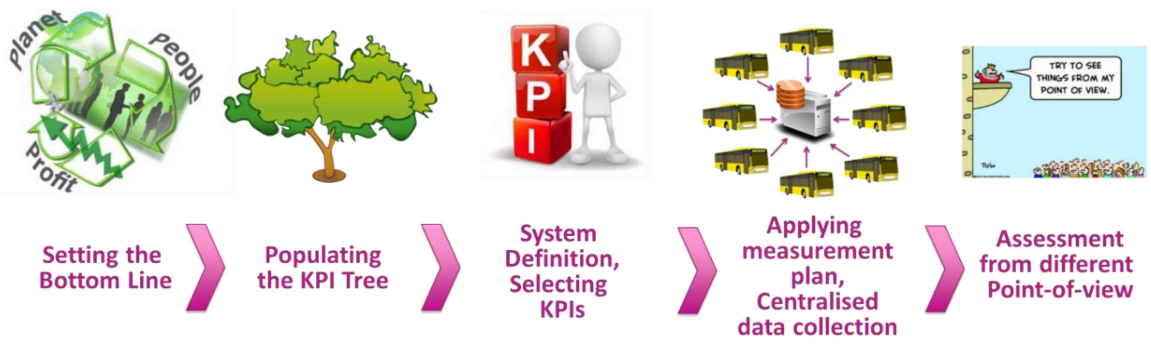

Figure 1 - The five-step process for Global Evaluation in ZeEUS.

3.3 Setting the Bottom Line

For setting the base for the global-level evaluation of the ZeEUS demonstration activities, a **Triple Bottom-Line** (TBL) **concept was chosen**. It has been first articulated by Freer Spreckley in /3/, and later made more widely known in the form of “People, Profit, and Planet” by John Elkington /4/, as the “Three Pillars of Sustainability”.

In this particular application of TBL, we have determined that **‘People’** refers to the impact on people in and outside of organisational structures involved in this project. It should look after fair and beneficial business practices toward labour and the community and region, in which an organization conducts its business. Relevant KPIs for this group are people involved in administrative activities, new employment opportunities generated, and the number of people (like the passengers) affected by the solutions.

Furthermore, in our analysis **‘Profit’** is the economic value created by the organization after deducting the cost of all inputs, including the cost of the capital tied up. In this case the financial gain can include also new initiatives increased market opportunities.

Consequently, **‘Planet’** covers the environmental dimension that makes up the green solution: exhaust gases such as CO_2, NOx, and particulate matter (PM), as well as use of various resources, renewable or non-renewable. It should also foster sustainable environmental practices, benefit to the natural order as much as possible, or at the least do no harm and minimise environmental impact.

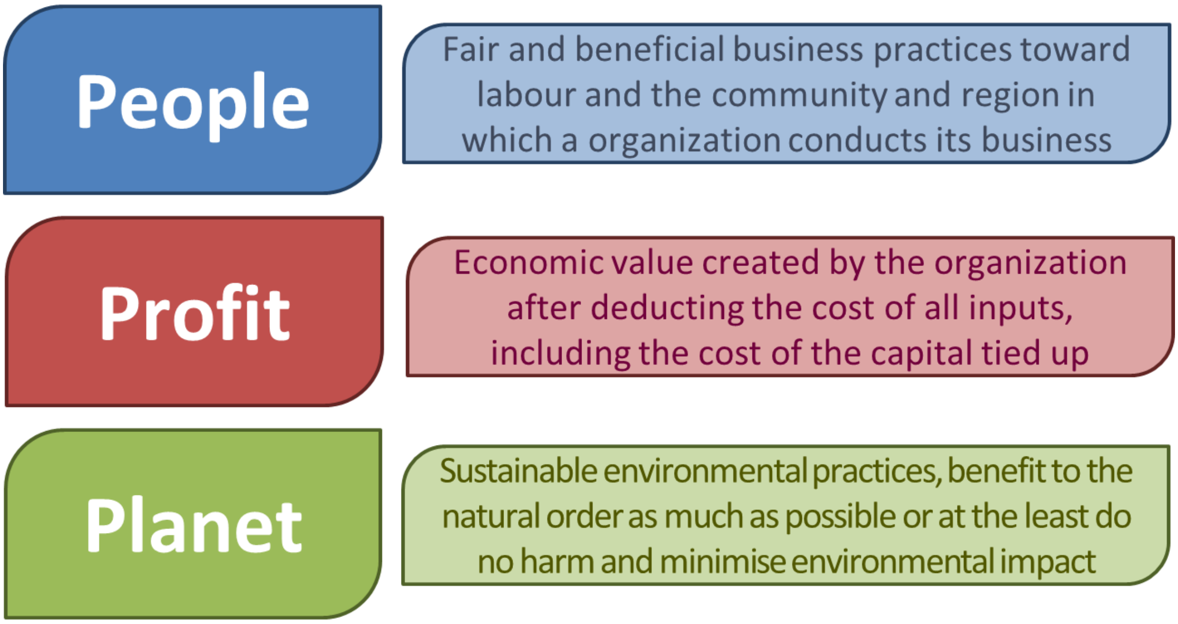

Figure 2 - Triple-Bottom Line concept for Global Evaluation in ZeEUS.

3.4 Selecting the Roots and Populating the KPI Tree

3.4.1 Requirements for KPIs

A KPI is the **most important performance indicator** to measure and follow in order to make effective analysis of the success or a failure of the activity or the process that is under analysis. KPI is the highest-level indicator among all performance indicators (PI), and is often aggregated from a list of lower-level PIs. Furthermore, PIs are also composed of several parameters, each measured separately. Thus, when choosing PIs, understanding the hierarchy and interactions of the components and indicators in a system is important, and one must be able to track the ”root causes” for the indicator’s behaviour in order to choose right parameters to be measured and right KPIs to be followed.

When populating the KPI tree, the **independence** of each branch throughout the tree must be guaranteed, to prevent the overall analysis from being biased by the super-imposition of effects. Indicators need to be independent from each other, i.e. not bring the same information or represent partly or entirely the same performance. This means that the list of KPIs provided could be grouped to meet this precondition.

The **root will be populated with further branches** (in principle to be located under the current nodes), to cover the specific characteristics of the bus systems. When building the tree, one must also recognise that **some parameters** (to be measured) **will reflect their behaviour in multiple indicators**. As an example, one may consider passengers volume, which will be a component of the revenues, or energy efficiency, which will further influence costs, or the size of the investment, influencing even the leverage.

Eventually, the list of indicators has to be **exhaustive,** and has to prevent that other indicators, which cannot be reported or easily converted to the selected ones, are used in the performance analysis and evaluation of each demonstrator.

Furthermore, main criteria could be defined and allocated to separately assess all three essential areas of investments in an electric bus system, i.e.:

- **Infrastructure** investments,
- **Vehicular** investments,
- **Operation-based** investments.

In principle only a sub-set of criteria would be significant for each type of investment.

3.4.2 Populating the KPI Tree

Following the above-mentioned set of guidelines, the roots of the KPI Tree and subsequent branches were **built mostly on the basis of engineering judgement** and analysis of the electric vehicle and complete bus system, and **taking into account all such items that could contain a potential change or difference with today’s bus systems** using predominantly ICE-powered busses.

Moreover, when proposing indicators we also needed to take into account that at least **some of the indicators are** necessary not just for assessing the performance of the demonstrator, but **also valid for comparison in before-after analyses**, allowing the evaluation of different technological options, i.e., both the one currently in use and the demonstrated one, which will likely replace (or be an alternative to) the existing one.

In the process each **Bottom Line** was articulated in 3 levels (See Figure 3):

- The **Root** is the highest level (each Bottom Line can be divided in Roots),
- The **Branch** is the secondary level (each Root can be divided in Branches),
- The **Sub-Branch** is the lower level (each Branch can be divided in Sub-Branches).

All the KPIs can be allocated to one of these levels.

At this stage whether it will be possible to record and manifest any change in all of the listed indicators during the time of the demonstration run was another issue. However, it was felt that despite of that, the indicators should be included, even if the analysis would become quite redundant.

Furthermore, it was felt that the **KPI-list needed to be as comprehensive as possible**, and so exhaustive that no essential indicator falls out of the list, because in the end, **we needed to support a variety of point-of-views, each needing their own particular sub-set of KPIs**.

The final form of the KPI tree for each of the three Bottom Lines are portrayed in Figures 4, 5 and 6. More refined and fully detailed versions are available in Annex 1.

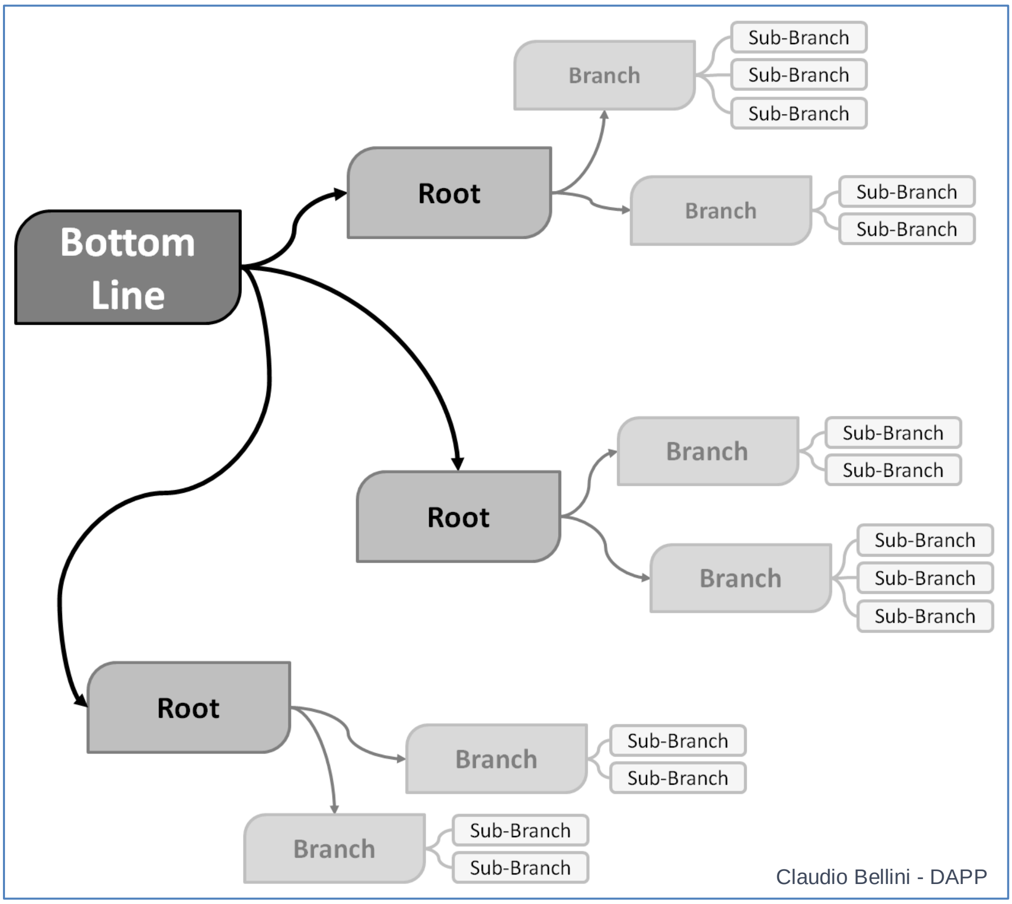

Figure 3 - General structure of each Bottom Line.

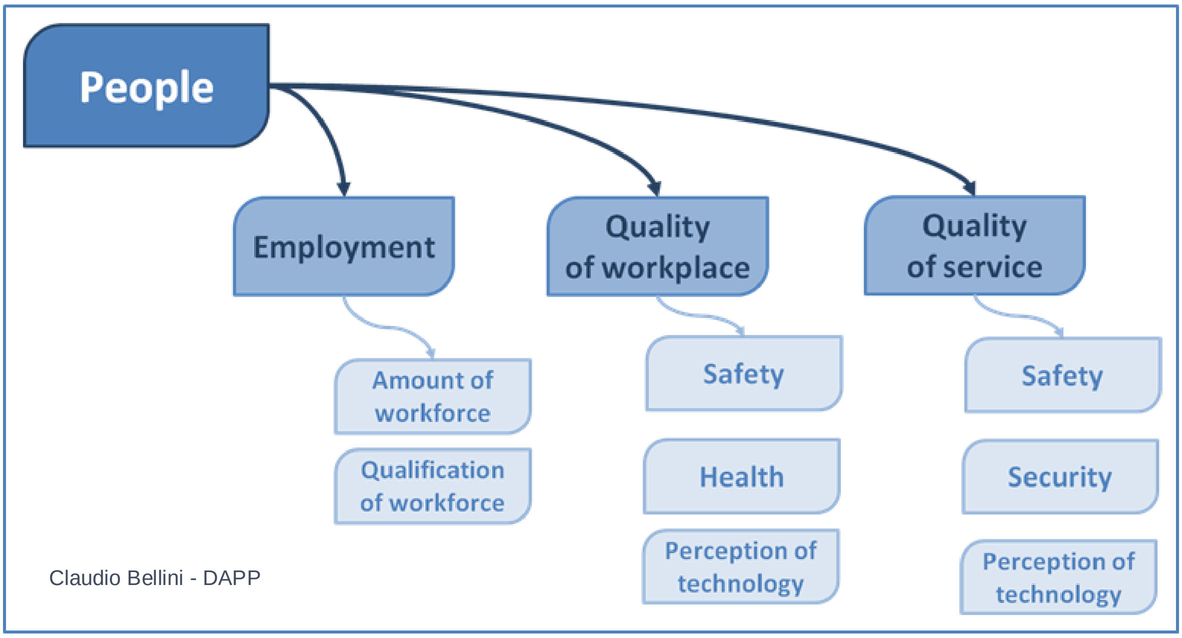

Figure 4 - Roots and Branches for "PEOPLE" Bottom-Line.

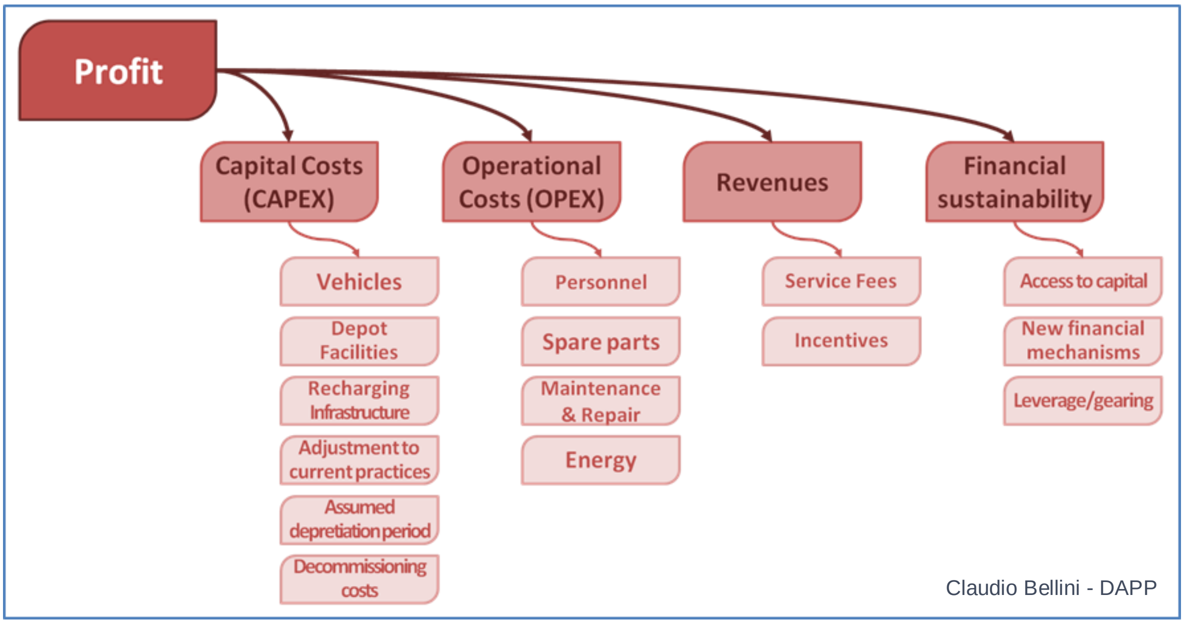

Figure 5 - Roots and Branches for "PROFIT" Bottom-Line.

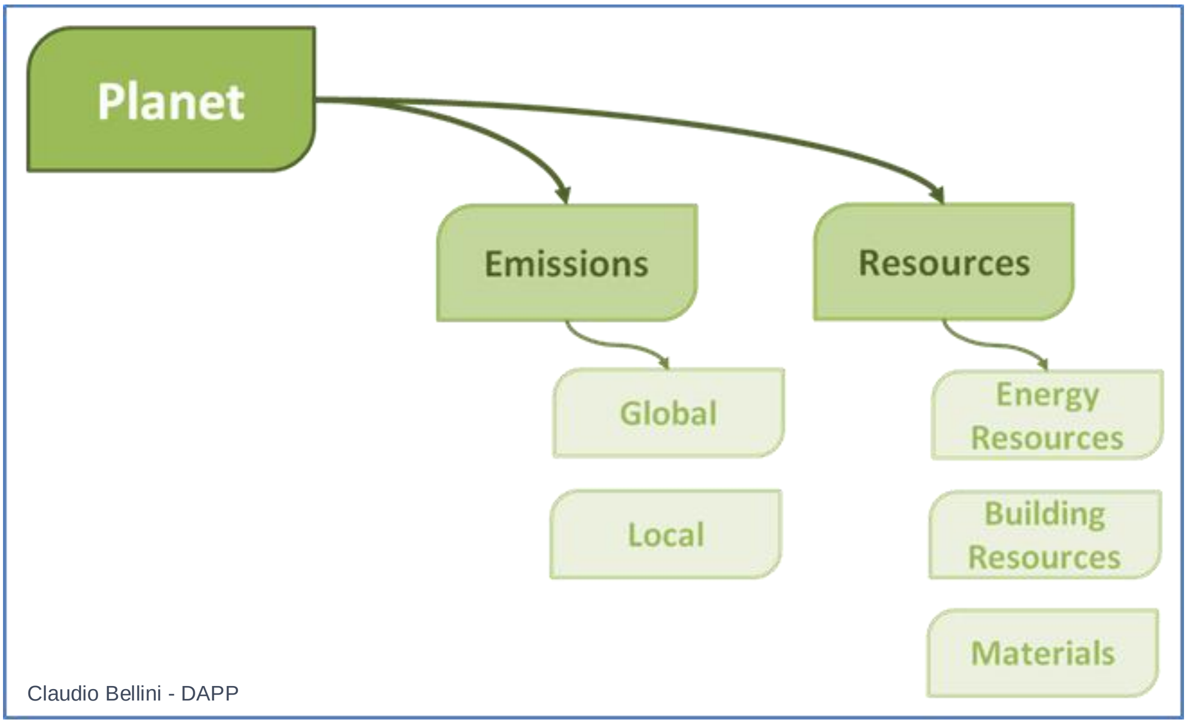

Figure 6 - Roots and Branches for "PLANET" Bottom-Line.

3.4.3 TECHNICAL AND OPERATIONAL DATA

In order to be able to report the selected KPIs many types of data are needed, as often one KPI is aggregated from many different pieces of information. Many important parameters are also related to the technical design and performance of the vehicles, but some are also derived from the operational framework itself, i.e. the characteristics of the locality (city) of demonstration and the architecture of the bus systems itself. This latter kind of information is highly necessary for the sake of transferability of the results, as in many ways success or failure is related to the surrounding conditions and circumstances, rather than just the technology implemented in the demonstration.

For this purpose the joint evaluation team listed data that needed to be collected for the above mentioned reasons, and divided the parameters according to their origin, i.e. the base where the data will be collected.

These bases, depicted also in Figure 7, were:

- System (lines, operations etc.)
- Vehicle (bus and its on-board subsystems)
- Energy and/or Fuel Consumption
- Charging System
- Dependability/Availability

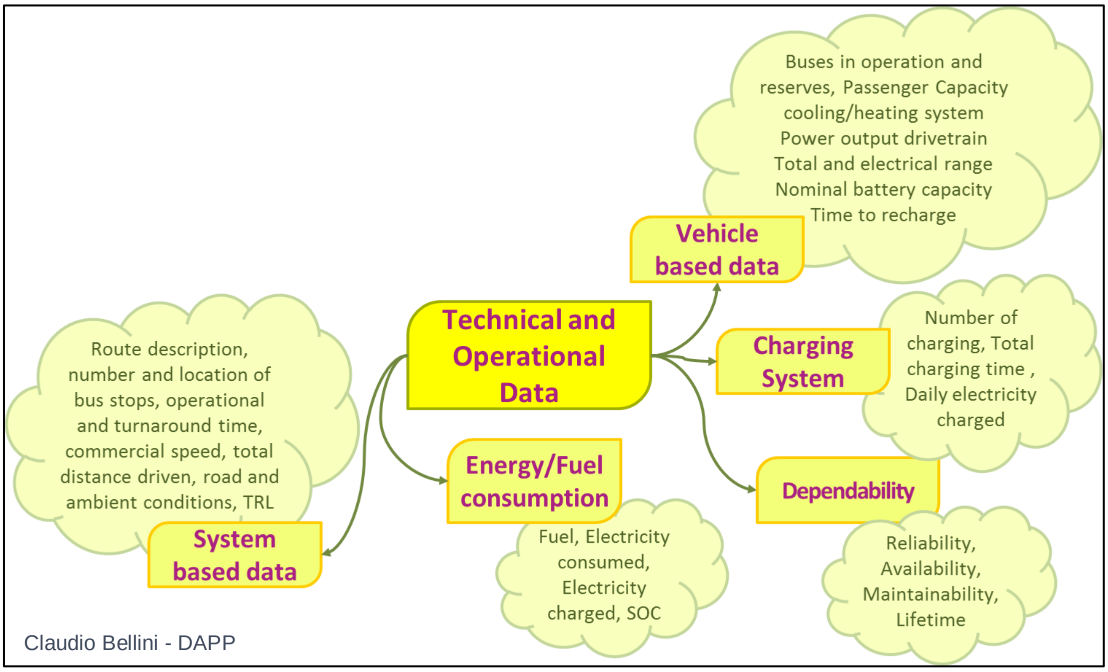

Figure 7 - Main branches for Technical and Operational Data.

As the last stage of the KPI development process the Liaison Bodies, i.e. partners acting as the scientific support and local evaluators of each demonstration, were asked to:

- checked the clarity of each single KPI, with the aim of understanding exactly, what information is requested, and checking if the description text is adequate and unambiguous;
- eventually made comments and proposals for improvement and clarification;
- preliminarily, checked availability and applicability of the data for KPIs pertinent to their specific demo situation

In this stage of the process, we also came across to the fact that the data that is to be collected to feed the performance indicators comes from various origins that are somewhat nested, and **all pieces of information** (or data) **have an "owner"**.

Understanding this "ownership" of the data is very important, because when setting-up the data collection structure and choosing the indicators, one has to assure that the necessary information can be obtained. However, especially in a PTA/PTO -type of arrangement, there may not be direct access to all pertinent data, because e.g. a PTO decides that certain information of their operations is confidential, as it can give out too much of their business performance.

Thus, **in a procurement case the tender must specifically list what information the service provider is obliged to disclose, and the purpose and eventual use of that data**.

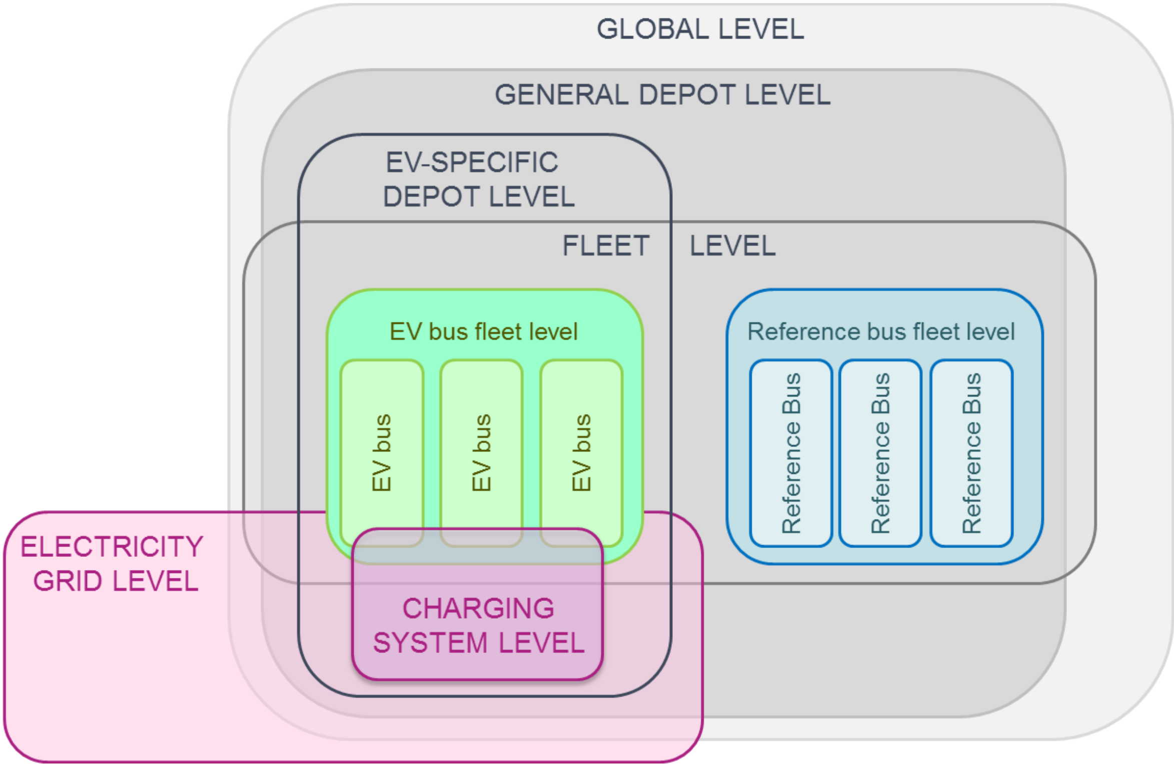

Figure 8 - Nested levels and origins of the Data.

3.5 System Definition

One of the most important findings of the ZeEUS is that **electric busses cannot be treated as vehicles alone, but the charging infrastructure and energy supply must also be considered** along the vehicles. Together **they form a system**, and when we add the operational procedures, we come to a **process**.

System definition is essential for successful selection of KPIs and their implementation, because **KPIs need always to be closely related to the activity or process** that is being monitored

Regarding the choice of right KPIs it is vitally important to be able to correctly define the system that we are working with, because the indicators that we choose must bear a direct link to the specific characteristics of the case in question.

Taking into account both the buses as well as the charging infrastructure, one can combine them with many different ways, and each combination has its particular features that need to be accounted for, when choosing KPIs.

In ZeEUS, several different combinations of bus and charging hardware technology were demonstrated. Figure 9 illustrates these basic combination of bus and charging schemes.

In principle, amongst the core seven demonstrations there were five basic use cases:

1) Overnight conductive charging, depot based (Barcelona, Bonn)
2) Opportunity charging with conductive pantograph at terminals (Pilsen, Munster)
3) Opportunity charging with conductive pantograph from catenary lines (Cagliari)

4) Opportunity charging with conductive pantograph at terminals + fuel (Stockholm)
5) Opportunity charging with wireless, inductive pick-up at terminals + fuel (London)

As an added characteristic feature, the Pilsen, Munster and Stockholm cases all used different pantograph concepts. In Pilsen, the pantograph raised from the roof of the bus to the charging dome, whereas in Stockholm an inverted pantograph was used. In Munster the first approach was a novel-type of sideways contact device, but during the course of the project this was changed to a regular pantograph.

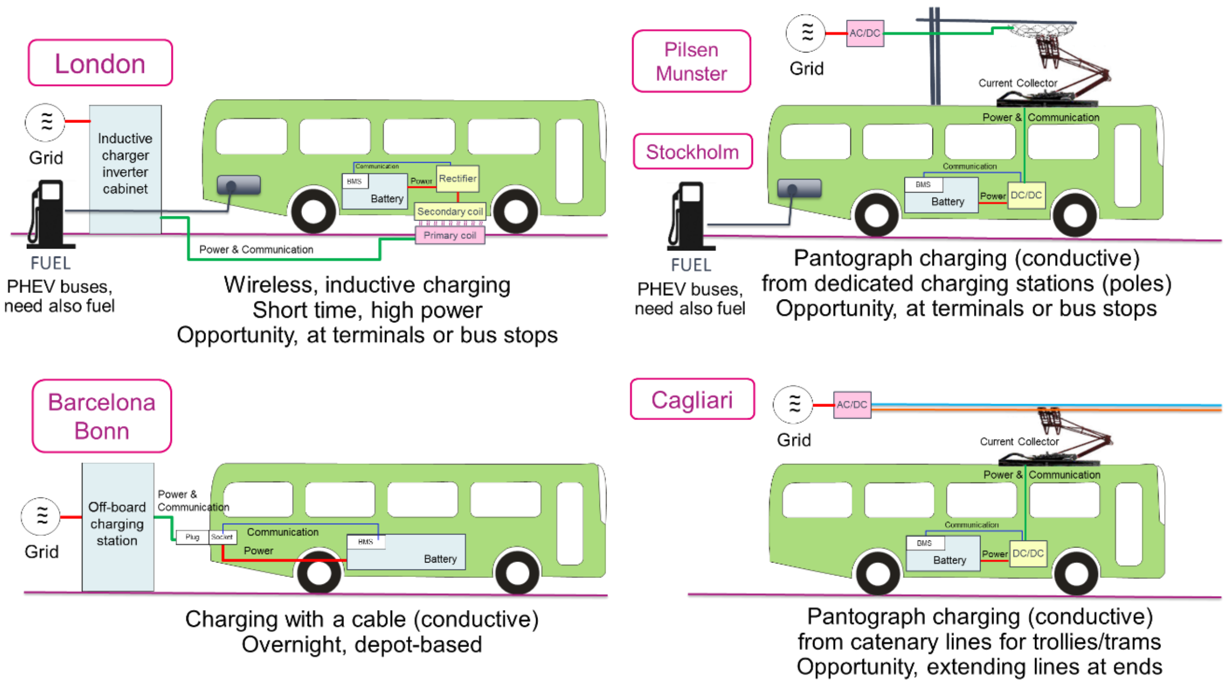

Figure 9 - Different bus and charging hardware/schemes demonstrated in ZeEUS.

3.6 Demo-specific selection of KPIs

Altogether, the process resulted in a quite comprehensive list of indicators: 185, of which 35 were for “People” bottom line, 53 for “Profit” bottom line, 26 for “Planet” bottom line, and 71 for Technical and Operational Data.

Of this list no single KPI was considered as mandatory, but each demonstrator could choose the KPIs, depending on the characteristics of the implemented electric bus system (e.g., extension of the case, technologies applied, current operation, etc.). However, all KPIs eventually chosen should be taken from the complete list. Furthermore, for the benefit of successful global and horizontal analysis between the demonstrators, as many common KPIs as possible should be available.

From that complete set of KPIs, the Liaison Bodies were asked to select indicators for each different demonstrator, in a way that they are usable for assessing the performance of the demonstrator, and valid for comparison in before-after analyses, allowing the evaluation of different technological options, i.e., both the one currently in use and the demonstrated one, which will likely replace (or be an alternative to) the existing one.

After choosing the indicators, usually with a negotiation amongst the demo partners, all the Liaison Bodies indicated for each selected KPI also the following:

- Level of confidentiality
- Data owner
- Data source (measurement, survey or other)
- Data collection frequency (whether the data can be provided on a daily, monthly or annual basis, or if it is a one-time entry, e.g. specification data)

This part of the process was very important on the local, demo level, because the Liaison Bodies of the demonstrators interacted with the other partners (operators, manufacturers, authorities) and sought their commitment to install any required device, perform the measurements, collect and disclose the data, and eventually positively contribute to the analysis of the results in a later stage of the project with those, who will take the decision to invest further in the demonstrated solution.

The statistical evidence of the information was supposed to be ensured by a long-term collection of operational data in order to have a large basis of data for the evaluation.

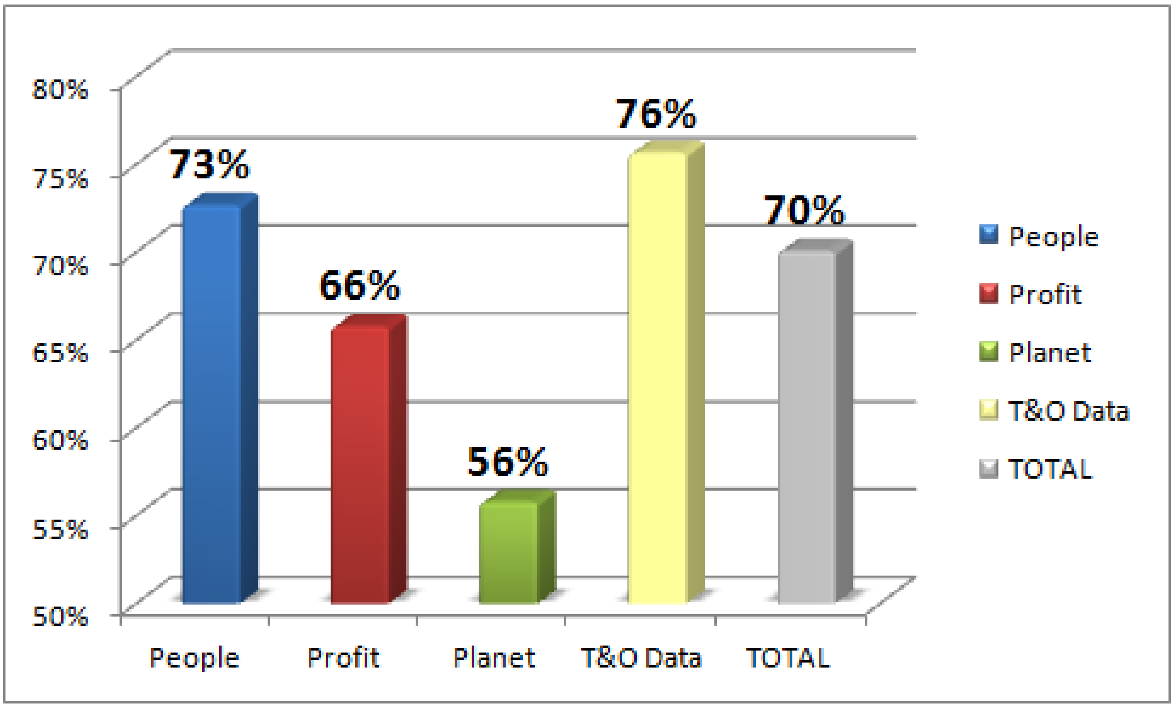

Figure 10 - Overview of the demo-specific selection (7 CORE-demos only).

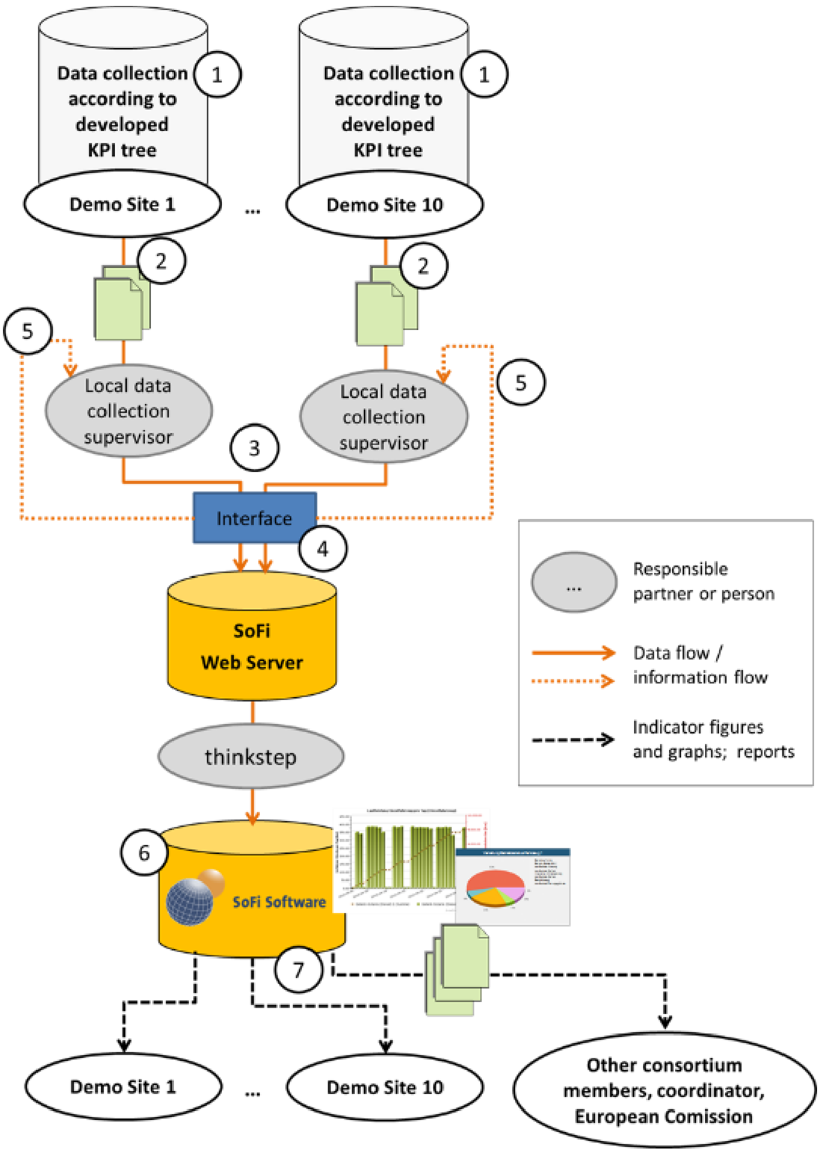

Figure 11 - Measurement and centralised data collection process.

Applying Measurements and Data Collection had several stages:

1. Data collection at each demo
2. Provision of data sets in agreed format by local data collection supervisor
3. Data provision to SoFi using a customisable interface
4. Plausibility checks
5. Feedback on data quality (in/out of spec)
6. Data analysis by end of following month, visualisation and regular reports
7. Data analysis results available for consortium partners, coordinator, EC, project officer etc. with varying level of aggregation and anonymization as needed

3.7 Assessment from different point-of-view

Point-of-view has a definite influence on the selection of KPIs and their evaluation, as targets and objectives differ clearly, depending on who's the point-of-view is, and selection of KPIs is always strongly related to both.

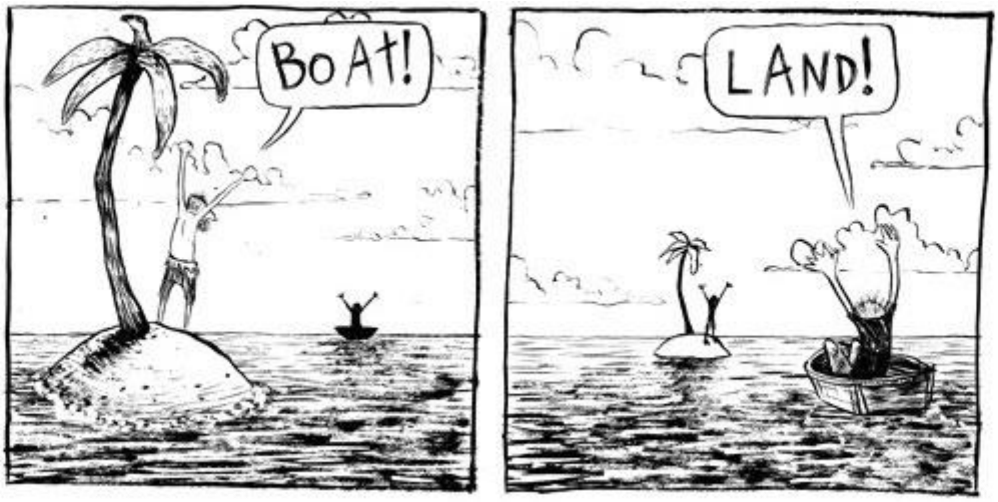

Figure 12 - Point-of-view has definite influence on KPI selection.
(Original artist unknown)

In the framework of ZeEUS, we have identified **four different main stakeholders that have different point-of-view to the process** of public transport services by buses with electric (or hybrid electric) propulsion.

These stakeholders are:

- City/Municipality
- Public transit authority (PTA), if exists in the framework
- Public transport operator (PTO), or equivalent actor in city/municipality
- Users

Each of these stakeholder types have their own set of targets and preferences and, thus they have **different priorities and most important core KPIs**.

For **CITY/MUNICIPALITY**, the main interests and priorities are usually related to issues of "common good", such as:

- High level of service vs. expenditures and incentives
- High utilisation rate of Public Transit services
- Good local air quality
- Local employment opportunities

For **PUBLIC TRANSPORT AUTHORITY**, the main interests and priorities are generally somewhat more focused, like:

- High level of service vs. imbursements
- High utilisation rate of Public Transit services
- Good user acceptance

For **PUBLIC TRANSPORT OPERATOR**, the focus is usually in economics and operations, like:

- Low OPEX/CAPEX
- High level of service vs. expenditure
- High utilisation rate of vehicle stock
- Flexible use of workforce

For **PUBLIC TRANSPORT USERS**, the important features to follow and esteem are related to the functionality and quality of the service, such as:

- Easy access
- Frequent and punctual service
- High level of service vs. affordability
- Low noise level inside

3.8 Evaluation of the KPI

While implementing an evaluation scheme and selecting KPIs, all these "voices" should be heard and catered equally, because public transportation is very much a joint effort, and no party should have an overruling position. In order to success in this endeavour, it is most **important to identify those indicators that are shared by most stakeholders**, as **those should be the real key indicators to be followed**.

This identification process could be accomplished by letting a fair number of people of each of the stakeholder groups to choose and/or rank the indicators, and then calculate an index for each indicator based on "votes" from each stakeholder group.

The Joint Evaluation Team tried to carry out this kind of "priority selection and ranking process", but was not successful in reaching enough respondents of each type of stakeholder. Especially the "user perspective" was very narrow, and limited only to the surveys undertaken by some of the demonstrations. However, we managed to get a ranking for the indicators from most of the core demonstrations. Depending of the case, it was resulting from a joint process involving the demo partners, but sometimes it was based only on the perception of the scientific partner (Liaison Body). Furthermore, the Joint Evaluation Team completed also their own ranking process.

Table 2 shows the combined results of the scoring exercise, broken down to the scores of the Joint Evaluation Team (JET) and the average for the demonstrations. The table shows the total number of KPI that were listed for each of the bottom lines and the number of high scoring indicators (>2, out of 3) for the Joint Evaluation Team and the Demonstrations, as well as the percentage of the high scores of the total.

Table 1 - Results of the KPI scoring exercise; number of High Scores

Bottom Line	TOTAL	Joint Evaluation Team		Demonstrations	
PEOPLE	31	6	19%	5	16%
PROFIT	34	15	44%	18	53%
PLANET	17	7	41%	11	65%
TECH	83	50	60%	68	82%
TOTAL	165	78	47%	102	62%

NB: the total number of KPI's in this exercise was not the same as the total list (185)

3.9 High scoring KPI per bottom line

3.9.1 PEOPLE

The highest scoring KPIs in PEOPLE bottom line were **the amount of workforce** (drivers, maintenance personnel), as well as the **qualification of the maintenance personnel** (JET only). Furthermore, **accidents to passengers, drivers or maintenance personnel** were also regarded important.

3.9.2 PROFIT

The high-scoring KPIs in PROFIT bottom line were **costs of vehicles, depot workshop facilities and tools**, as well as **costs of grid connection and chargers**. Furthermore, **wages and recurring training needs** were also marked with high importance. Unanimously **battery costs** were also marked, along with the **costs of energy for traction**, as well as fuel, if the demo concept was employing a hybrid bus.

Perhaps because this was a demonstration phase activity, all kinds of revenue were largely underrated.

3.9.3 PLANET

The high-scoring KPIs in PLANET bottom line were **emissions of carbon dioxide** (CO_2), along with the **air quality emissions** (NOx, PM) and **noise**. The demonstrations appreciated also the **length of zero-emission EV mode** and amount of hazardous waste as important indicators to follow.

Regarding use of resources, **share of renewable energy** (green electricity) and t**otal electricity use** were indicators marked with a high score. However, use of resources and materials were not appreciated.

3.9.4 TECHNICAL DIMENSIONS

The list of high-scoring KPIs in technical dimensions and operative parameters was fairly long, as the Joint Evaluation Team marked 60% of the 83 available KPIs as highly important, and the demonstrations choose even more, 82%. Therefore, the proposed list for measurement plan and data collection seemed quite well developed and appropriate.

4. A SHORT PRIMER TO KEY PERFORMANCE INDICATORS

4.1 Composition of a KPI

Key performance indicator (KPI) is a type of **performance measurement,** whose purpose is to **evaluate the success rate** of a particular activity or process. Key performance indicators are also **objectives to be targeted that will add the most value** to the business or other operations that are scrutinised.

Broken down, a KPI consists of three equally essential items that are:

- **Key** = a major contributor to the success or failure of the process; something that “makes or breaks” the whole thing
- **Performance** = a metric that can be quantified, adjusted and controlled
- **Indicator** = an easy-to-read representation of present and future performance

4.2 Types of KPIs

Performance indicators **can be divided into several different categories** /1/, such as:

- **Quantitative** indicators that can be presented with a number
- **Qualitative** indicators that cannot be presented as a number
- **Leading** indicators that can predict the outcome of a process
- **Lagging** indicators that present the success or failure post hoc
- **Input** indicators that measure the amount of resources consumed during the generation of the outcome
- **Process** indicators that represent the efficiency or the productivity of the process
- **Output** indicators that reflect the outcome or results of the process activities
- **Practical** indicators that interface with existing company processes
- **Directional** indicators specifying whether or not an organization is getting better
- **Actionable** indicators are sufficiently in an organization's control to effect change
- **Financial** indicators used in performance measurement and when looking at an operating index

Furthermore, there are **two fundamental types of KPIs**: ***outcomes*** and ***drivers***. The Outcome KPIs are also characterised as *lagging indicators*, and they measure the output of past activity. Often they are financial in nature, but not always. Examples include revenues, margins, return on equity, customer satisfaction, and more in terms of bus transport, we can say that “level of service” or “keeping the timetable” are outcome-type of KPI’s.

In contrast, the Driver KPIs, also classified as *leading indicators* or *value drivers*, measure activities that have an impact on outcome KPIs. These driver-type KPIs measure and portray activity in its current state. However, on a time series, one can see the effect, which the interlink between divers and outcomes creates, and if sufficient amount of data is available, one can build even a mathematical formula between the driver-KPIs and outcome-KPIs. A very basic example of driver-type of KPI in bus transport is “availability of bus”, because it can influence the “level of service”, as an output-KPI. There ought to be a balance between driver-type and output-type KPIs, slightly favouring drivers over outputs for better understanding and controllability of the process.

4.3 Characteristics of Effective KPIs

According to Doran /2/, a good KPI needs to fulfil five essential requisites:

1) It must be **specific**, clear and focused
2) It must be **measurable**, preferably quantifiable in numbers
3) It must be **achievable**, i.e. the target-setting is reasonable
4) It must be **realistic**, and directly pertinent to the process
5) It must be **time-based**, to be measured over a time period

To be really successful a **KPI needs to be based on high-quality and dependable data** that is:

- Accurate, Precise and Reliable
- Available and Timely
- Consistent and Complete

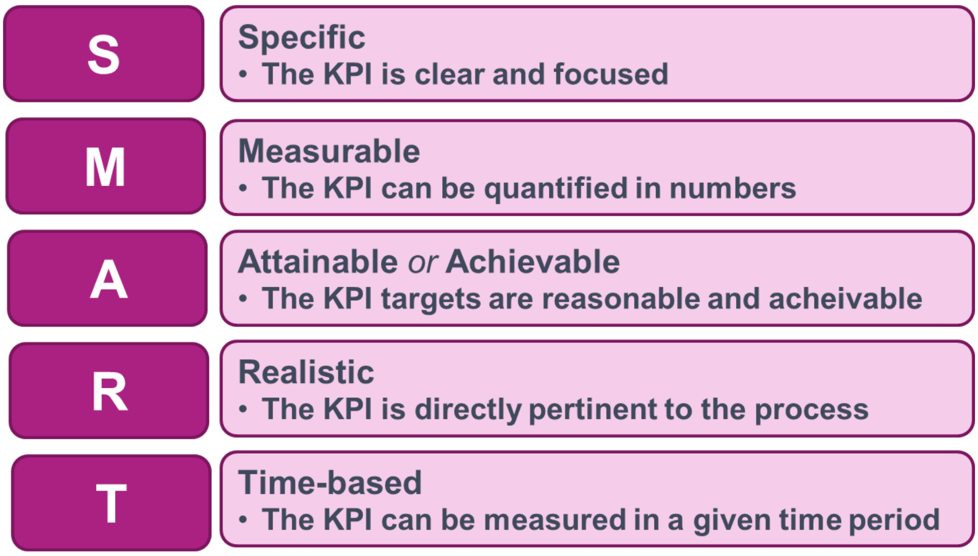

Figure 13 - “SMART” Key Performance Indicators (Ref: /2/).

According to Eckerson /5/, effective set of KPI has the following features:

1. **Sparse**: The fewer KPIs the better
2. **Drillable**: Users can drill into detail
3. **Simple**: Users understand the KPI

4. **Actionable**: Users know how to affect outcomes
5. **Owned**: KPIs have an owner
6. **Referenced**: Users can view origins and context
7. **Correlated**: KPIs drive desired outcomes
8. **Balanced**: KPIs consist of both financial and non-financial metrics
9. **Aligned**: KPIs don't undermine each other
10. **Validated**: Workers can't circumvent the KPIs

4.4 Levels of KPIs

Like the KPI tree that was constructed in 4.4, KPI's are layered or nested, so that the **root-level indicators** can be classified as "**strategic**", whereas the **branch-level indicators are "tactic"**, and the **sub-branch level indicators are "operational"**, and derived directly from the actions or technical features.

In practice this means also that **different indicators are useable also for different levels of the organisation**: strategic level indicators are meant for executive level, tactical for department level and operational indicators are adhered to workgroup or team level, for those that deal with day-to-day running of the activity. Usually, this "cascade" structure has two or three levels, but it can have even more, depending the complexity of the process or organisational structure.

As the number 1 rule above says, there should be as few KPIs as possible. However, that can and should also be realised the way that it does not specifically limit the total number, but rather the number on each level of and operations. In practice, each level can handle about 20 KPIs /5/. Counting in the nesting and sharing of indicators between the levels, this would mean that a three layer system consists of some 50 different KPIs, and a four layer system could easily populate 60 to 70 indicators, and still be manageable.

Furthermore, the rule 2 about "drillability" necessitates the information and indicators to be chained the way that one can dig into details that are behind a higher level KPI. The structure of the KPI tree helps to understand the dependency of the different level indicators, and their interdependencies. This kind of structure helps to understand, "what drives what", i.e. what is the input and what is the output, and what we need to do with the inputs to get the desired output.

If the number of KPI's is higher than a few, **it is customary to create a "dashboard" that portrays the values of the chosen KPIs in a format that the user can easily adapt to**. Rather than displaying just plain numbers, one can enhance the information with colour, so that if the indicator is on a target level, the colour can be green or blue, but if it is "off-course", the colour changes to orange, and in a critical situation to red. Furthermore, **using graphics like bars or line plots is also a common way of dressing the information** the way that is becomes very **easy to see by just a glance, how things are going**. Of course this dashboard is built around only those KPIs that are adhered to the level of the user, even if the complete structure and back-office system behind each dashboard is the same.

4.5 Quality and appraisal value of indicators

As already postulated in 5.3, all KPIs need to be based on solid, dependable and high quality data. However, in practise this may not be so easily catered, as in-system dependencies can create skewness and distortion, because sometimes "things go hand-in-hand", and it can be difficult to measure and handle some variables individually.

In fact the challenge and difficulty in using driver-type indicators to monitor performance, i.e. output-type KPIs, lies in the fact that usually the output-indicators are aggregated and influenced by several different sub-level driver-type indicators and other variables that may not have chosen as indicators at all. As an example, energy consumption of a bus is of course dependent on its design, but on day-to-day operational level there are at least five major elements that have influence on it. Figure 14 portrays those elements to be traffic situation (fluidity of the flow), passenger occupancy, characteristics of the route, use of auxiliaries and HVAC (heating, ventilation and air conditioning) systems, as well as the driver.

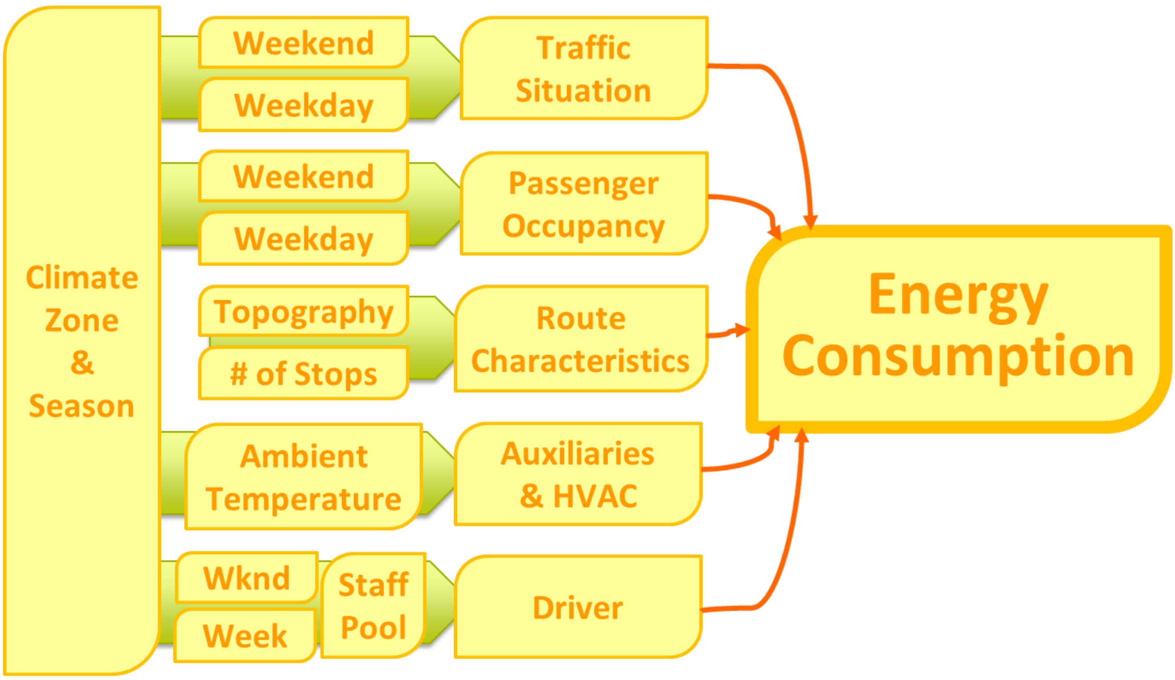

Figure 14 - Drivers for energy consumption in an electric bus.

Furthermore, in practice, all of these main level attributes have all some underlying aspects that have influence, and there can be even further layers, as depicted in the Figure. For example traffic situation is usually different on weekdays than weekends, and furthermore, the season has also a sub-level influence. Apart from the basic route characteristics, season and climate zone have influence on energy use via many primary-level factors. The most obvious is or course the use of HVAC, which is driven by the ambient temperature, but actually there are also seasonal variations in traffic fluidity, passenger count and even the drivers, as due to vacations, the staff pool changes and different drivers may drive the buses in summer than in wintertime.

Of course these influences are usually quite diminutive, but anyhow they create certain "noise" to the data, but with a lot of good quality data, current assessment systems are able to scale these effects. However, if there is e.g. no system to record the driver information, the task of addressing the influence of each aggregator to energy consumption comes quite difficult, as it is known from practical experiences that difference between drivers can be some 10%, and if the driver is not differentiated, the "noise" becomes quite high.

Moreover, the energy consumption is quite often *per se* one KPI, but it also reflects to other indicators, mainly financial in the form of running costs and OPEX. However, as Figure 15 portrays, it has also a certain "spill-over" effect because energy consumption is directly reflected in the charging time, and that can influence the time split between operational and non-operational, as well as usage rate of the charger. Eventually, those can trigger changes in wages paid and charger maintenance needs, both attributing to OPEX, but only on a slight level.

Furthermore, the electric energy consumption can also attribute the emissions avoided, but at present, this is mainly a "goodwill" type of influence, as the emissions are usually not given any direct monetary value, even if the present Clean Vehicles Directive does contain basis for such valuation, giving monetary values for tons of pollutants (mainly NOx and PM).

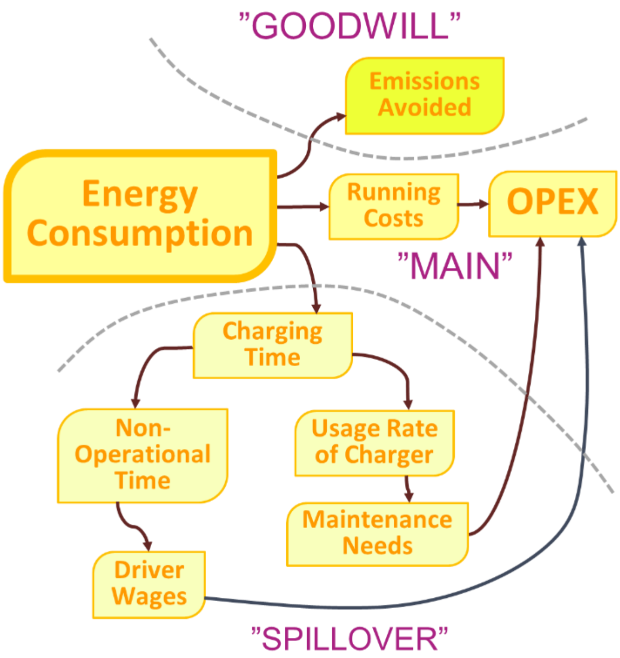

Figure 15 - The consequent effects of energy consumption in an electric bus

There is clear interlinking and cross-effects between KPIs in different bottom lines, as Figure 16 shows an example: if more workforce is needed and their qualifications are higher than before, this has an effect also on the wages and amount of training necessary to keep the qualification levels on par with the requirements.

This is somewhat in contrast to the need set in 4.4 about the independence of each branch in order to prevent the overall analysis from being biased by the super-imposition of effects. Even if we strive to select indicators that are independent from each other, it is difficult to avoid these “spillage” effects between the branches.

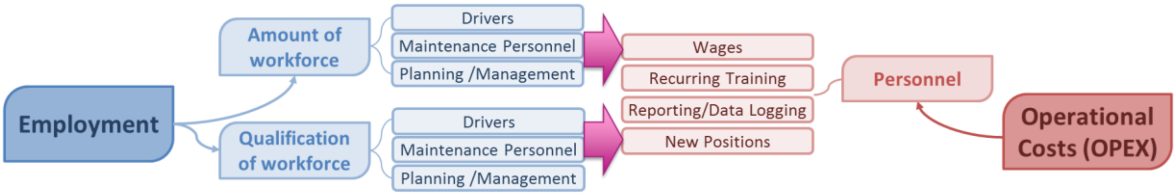

Figure 16 - The interaction between Employment and OPEX

5. GUIDELINES FOR PROCUREMENT AND TENDERING

5.1 Preamble

In this context it is supposed that the procurement and tendering refers to acquisition of public transport vehicles or services, involving the use of electricity as the main propulsion energy.

5.2 Procedures for procurement

Procurement is usually a circular rather than linear process involving several steps, as portrayed in Figure 17.

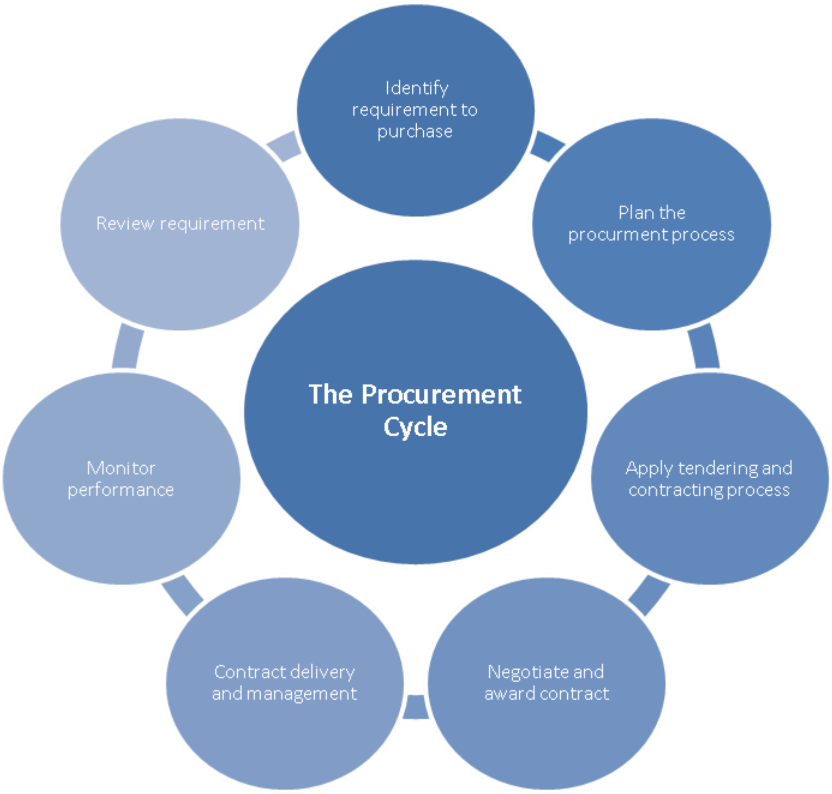

Figure 17 - Procurement process cycle

Source: http://www.eyota.com.sg/pages.php?mid=3&sid=15

As the Figure suggests, towards the end of the process the last steps usually involve review of the requirements, assessment of the performance and overall success rate, in view of refining and re-defining the set of requirements and other features for the purpose of improved performance in the next procurement case or round.

Regarding procurement of public transport vehicles or services, the way of conducting the process depends of the framework and organisational structure of the case in question.

CASE A: PTA/PTO arrangement

In the existence of a Public Transport Authority (PTA), **the procurement is of services.** In this context the PTA usually releases Invitations to Tender in public, and Public Transport Operators (PTO) file their offers, noting what has been written in Terms of Reference (TOR), usually released with the Tender notification. Once the bidding time has ended, the PTA goes thru the bids, and ranks them according to the pre-released methodology described in tender documentation, and the contract is awarded for the highest-ranking bid.

CASE B: Public transport company

If the public transport services are not organised by a dedicated PTA, but are produced by the city or municipality via its own dedicated public transport services company, or a department of its own organisation, the procedure is different, as then **the procurement is of vehicles and their support systems**, like charging infrastructure. However, fairly similar open and public tendering is usually executed like in CASE A.

Nevertheless, it can also be possible to use Request for Proposals (RFP) instead. RFP is usually used when the promoter knows what it wants to achieve, but would like prospective partners/bidders to use their experience, technical capabilities and creativity to identify how the project objectives can best be met.

One of the main differences between an RFP and an invitation to tender is that in an RFP the promoter is looking for value (that is, operating efficiency, cost-saving measures, innovations and so on), rather than the lowest bid. /6/

CASE C: Private public transport company (PTO)

The private public transport companies are the third case to consider, and then **the procurement is** also **of vehicles and their support systems**, like charging infrastructure, as with the public companies. However, as the procuring promoter is a private patron, **the process does not require open Invitation to Tender or RFP**, but the promoter can address any individual, potential supplier the way the management has chosen. However, it is quite normal to use RFP, but the private company has more freedom in choosing the bid, and has freedom to negotiate with the bidders even after the bid time has closed.

A private company has also the freedom to use methodology called Selection in Planning (SIP), where suitable vendors and contractors are identified and contacted, and then the parties start working together to develop the solution, and eventually make contracts to attain it. SIP suits well to cases where requirements are subject to ongoing changes or where the development of a project or procurement exercise is expected to be implemented gradually. In such circumstances SIP would be better than issuing a formal tender /7/.

Regarding the procurement of novel and fast-developing technology with only a few potential and eligible suppliers, the most challenging case is certainly CASE A, as it requires very strict prescriptions of the products and services under procurement to be published in TOR as part of the tendering documentation. Furthermore, one has to specify ahead, how the choice between the bids will be made.

CASE C is most flexible, as its uses the RFP and bidding phase as a start-up, and allows the promoter and bidder (or bidders) to work together in the negotiations phase to find the most satisfactory solution for the need. **CASE B falls in between these two**, but is actually very close to CASE A.

5.3 Charging systems challenge open bidding process

Electric buses are a novel and fast-developing domain, and at present there not so many potential and eligible suppliers. Because with electric buses you cannot just acquire vehicles, but eBuses need also a supporting infrastructure in the form of charging system, the complexity increases dramatically over the existing case with ICE-driven buses. Therefore, if the procurement involves an open tendering process, a good amount of preparatory work and drafting is needed to come up with an appropriate TOR to be used.

Naturally, the easiest solution to this infrastructure issue is to leave it totally to the operator to arrange, but this only applies, when services are acquired (CASE A). There are already such cases in operation, where the operator has the charging infrastructure on its own premises at depot, but this arrangement may not prove to have the best cost-effectivity and total costs, as either the buses need a very large battery, which is expensive and can lower passenger capacity, or extra buses are needed, should the buses have to come to the depot over the day, as well.

If the choice is to start building a distributed charging infrastructure for opportunity charging at terminals or where several lines cross, the challenge is in choosing the best-suited system and vendor, because at this stage the level of standardisation is still quite low, and there are only a few suppliers for the hardware. As an example: opportunity charging can be applied either with wireless, inductive power transfer (IPT), or with a conductive solution, where a pantograph is used to connect the bus to the “dome” of the charger. Furthermore, this pantograph arrangement can be either “top-down” (pole mounted) or “bottom-up” (bus roof mounted). Figure 18 depict for some examples.

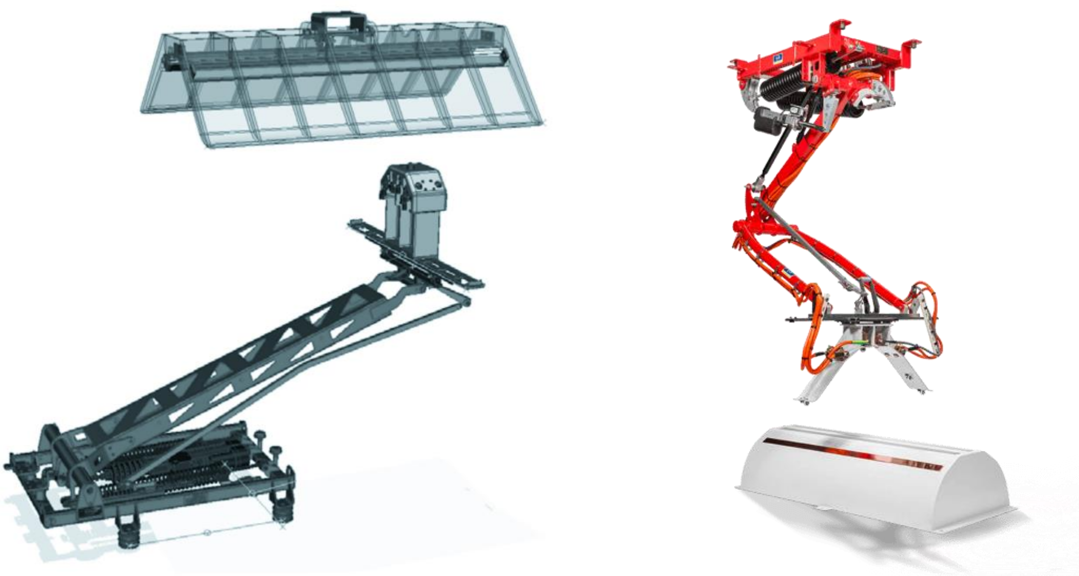

Figure 18 - Pantoragphs for eBus quick charging.

There are vices and virtues in both solutions. The advocates of the “top-down” or “inverted” pantograph say that the mass of the connector rails on the bus are only marginal, whereas in the “bottom-up” case the whole weight of the pantograph (about 85 kg) is on the bus, and equals the mass of one passenger. In inverted systems the positioning of the bus is also somewhat less critical, as the construction allows more leeway in terms of position and angle of the vehicle towards the mast. Also, in case of pole-mounted pantographs, less costly hardware is needed, because the connector rails are much cheaper than the pantograph itself. On other hand, if a pole-mounted pantograph breaks down, it will take off the whole charger, but if a roof-mounted device is broken, it only involves one bus.

There are diverse solutions in practical use, but so far we have not yet gathered sufficient amount of experience to support any type. However, the choice of the system is far-reaching, as the architecture will govern all future acquisitions, because converting vehicles to another type is not cost-effective. This fact will also limit the relocation of the vehicles form one city to another, if the charging arrangements do not match.

5.4 Risk-sharing is costs-sharing

When new type of technologies are taken into practice, there is always the element of risk, as in the early stages of the products’ life, ill behaviour is usually encountered and problems may occur. However, public transit service typically runs with quite tight schedules and low headways, so it cannot tolerate much errors. In order to overcome this risk of unavailability of the bus due to some problems, there are usually back-up plans and extra vehicles that can replace the harmed bus. In case of charging system problem, arranging back-up is more difficult, especially in case of opportunity charging. The usual way to handle this kind of situation is to dimension the battery to tolerate dismissal of one charging event without unduly affecting the service, or to have some electricity-generating system on board, like an ICE and generator.

Nevertheless, these back-up arrangements increase the total costs, and in the early stages of the implementation, they are unavoidable. However, as the technology matures, procedures evolve and volumes of buses and chargers increase, the whole system begins to have more inherent fault tolerance, and the size of these “extras” and back-up systems diminishes.

On the other hand, avoiding and eliminating risks usually means added costs. The usual case is that the service provider takes sufficient precautions to lower the associated risks, and includes the costs in the charges. In an immature domain like eBuses and their charging, this can lead to over-amplified situation, where the costs of “no risk” can become disproportionally high to the detriment it avoids.

But, what if in the early stages of the learning curve the arrangement could be more in favour of “taking some risks”, but also “accepting some faults”. In practise this attitude would mean risk-sharing, and could lead in a positive situation regarding total costs, meaning also that the costs are in a way shared.

5.5 Selecting KPIs in contracting electric buses or bus services

When using and selecting KPIs in procuring and contracting electric buses of bus services, one has to be very careful. To make right choices, one must understand the innards of a complex system and know “what drives what”, because if a high-level KPI is used as metrics for service quality, one must always make sure that the sources, where the data is coming from and paths of information that is feeding this KPI are known, and the party in charge has the possibility to monitor also the root sources and make necessary adjustments, if necessary.

In other words: if any high-level output-type KPI is used to monitor the quality of the service, the operator must have control of the driver-type, operational KPIs. If there are more parties involved, it is important to choose the right KPIs to use as “tokens” for measuring/monitoring the propagation of value added in the process thru the chain of operations.

A good system definition and selection of right indicators should already be part of the TOR, as then the bidders could see, how their product or service is valued and how the value is monitored, and this should lead to a design of an effective product or .procedure. However, we must also remember, that the way something is measured and monitored, will always influence the process: “you get what you ask for”. Therefore, the system definition and choice of indicators have a crucial role in the framework.

6. SHORT SUMMARY OF OTHER AVAILABLE MCDA TOOLS AND ASSESSMENT METHODOLOGIES

6.1 Multi-criteria decision analysis (MCDA) tools

Electric buses and their charging infrastructure form a complex, multi-parameter and multi-attribute system, which is definitely a challenging entity for a full and thorough, as well as objective evaluation.

For such complex systems there are a number of multi-criteria decision analysis (MCDA) methods that have been introduced and used in practice. However, most of them have been designed to evaluate alternatives on one particular scale of measurement only, and in reality the alternatives are characterized by many attributes which, usually, correspond to different types of metrics and scales.

A limited literature review focusing on assessment and evaluation of alternative-powered buses and their operations in public transport context resulted to the following list of analysis tools that have been utilised in evaluating and comparing public bus transport vehicles and systems.

6.2 VIKOR

The VIKOR method was originally developed by Serafim Opricovic as a multi-criteria decision making (MCDM) method to solve a discrete decision problem with non-commensurable (different units) and conflicting criteria /8/.

This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the decision makers to reach a final decision. Here, the compromise solution is a feasible solution, which is the closest to the positive ideal solution (PSI), and a compromise means an agreement established by mutual concessions.

In /9/ the authors have implemented VIKOR methodology in comparing different alternative solution for urban bus propulsion. Altogether 11 evaluation criteria were defined, and experts from different decision-making groups (manufacturer, academic institute, research organization, bus operator) performed the multiple attribute evaluation of alternative vehicles, which considered 12 variations. Each of the groups had their own set of weights, but on average, the TOP3 criteria were “Speed of traffic flow”, “Air pollution” and “Vehicle capability”. The lowest average weight was given to “Energy supply”. Then, an analytic hierarchy process (AHP) was applied to determine the relative weights of evaluation criteria.

Within the evaluation process (Delphi method), the first evaluation results were presented to the experts for the second evaluation. They had to reconsider the performance values of each alternative-fuel mode and to re-evaluate the alternatives. Seventeen valid questionnaires were retrieved from the evaluation process.

As a result, the following sets of compromise solutions (by VIKOR) were obtained:

- Electric vehicles (three different modes) were in the set of compromise solutions with the weights given by ‘‘Bus operator’’, and by ‘‘Academic Institute’’;
- Hybrid electric vehicles, with gasoline and diesel engine, were the compromise solution obtained with the weights given by ‘‘Manufacture’’;
- Hybrid electric vehicle with gasoline engine, fuel mode CNG and LPG, and hybrid electric vehicle with diesel engine were in the set of compromise solutions obtained with the weights given by ‘‘Research Organization’’.

6.3 TOPSIS

Parallel to VIKOR, the author in /10/ used also a method called TOPSIS (Technique for Order Preference by Similarity to Ideal Solution, see /11/, /12/, /13/), which is one of the most popular compromise methods for evaluating and ranking different alternatives. According to /10/, TOPSIS defines the best option as the one that is closest to the ideal option (PIS, *positive ideal solution*) and farthest away from the negative ideal point (NIS, *negative ideal solution*).

The ranking results obtained in /9/ by the TOPSIS method indicate that the electric vehicles may be considered as the best compromise solution, and the hybrid electric vehicles may be considered as the second best compromise solution.

6.4 MAROM

A further method called MAROM (MultiAttRibute Object Measurement) has been introduced for MCDM in /14/, and it has been implemented in evaluation of alternative-fuelled buses by the same author in /15/. Although MAROM was also designed to be capable of involving mixed data, i.e. both tangible and intangible attributes, however, it requires that the non-quantifiable and quantifiable attributes be treated in different manners. /14/

In MAROM, the raw data, either elicited from experts’ judgments or arisen from physical measurements, are preserved for the computations in forms of binary variables, rank numbers and quantitative data depending upon their corresponding scale of measurement, i.e. nominal, ordinal, interval or ratio. This way, they are not subject to any arbitrary transformation onto a higher or a lower order scale. Hence, to eliminate the different units of measurement by standardization or normalization, can only put through within the same type of scale of measurement. These features of MAROM are fundamentally different to those of comprised by the TOPSIS method. /14/

In /15/ a comparison between TOPSIS and MAROM was made using the same basic data that was published and evaluated using VIKOR and TOPSIS in /10/. There were the same 12 different alternate-fuel/energy vehicle options considered, but the number of criteria was increased from 11 to 15, and some of the “old” criteria were somewhat redefined. However, according to /8/ the weights of the original criteria were always used, and allocated uniformly for the new, more explicit criteria. The intention was that using this slightly modified data base for the evaluation problem would provide more robust and reliable results. /14/

According to the author of /14/, it was not a surprise that the two methods produced rather different rankings and scores. However, he suggests that comparisons of the findings should be made very carefully. As a remarkable outcome, he points out the big differences in the ranks of the conventional diesel engine bus. The last position of the diesel engine in the TOPSIS rankings seems to be rather strange, as it's MAROM rank was 6.

It was also striking that there are significant differences in the priority scores of the alternative-fuel modes produced by the two methods, as the highest MAROM rank was for Methanol option, followed by the electric variants that were the highest-scoring alternatives in TOPSIS analysis. In closing, the author in /8/ believes that the MAROM ranking reflects better the situation existing at present time than that of TOPSIS. Furthermore, the same author has published a supplementary, scenario-based analysis in /15/.

6.5 Cost-benefit analysis

According to /16/ Cost–benefit analysis (CBA) is a systematic approach to estimate the strengths and weaknesses of alternatives (for example in transactions, activities, functional business requirements or investments). It is used to determine options that provide the best approach to achieve benefits while preserving savings. The CBA is also defined as a systematic process for calculating and comparing benefits and costs of a decision, policy (with particular regard to government policy) or (in general) project.

Broadly, CBA has two main purposes:

1. To determine if an investment/decision is sound (justification/feasibility) – verifying whether its benefits outweigh the costs, and by how much;

2. To provide a basis for comparing projects – which involves comparing the total expected cost of each option against its total expected benefits.

CBA is related to (but distinct from) cost-effectiveness analysis. In CBA, benefits and costs are expressed in monetary terms, and are adjusted for the time value of money, so that all flows of benefits and flows of project costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their net present value.

Cost-benefit analysis was implemented on hybrid and electric city buses in fleet operations in /17/. The analysis was based on an energy consumption analysis, which was carried out on the basis of extensive simulations in different bus routes. Five different full size hybrid and electric city bus configurations were considered in this study; two parallel and two series hybrid buses, and one electric city bus. A conventional diesel city bus was used as a reference.

Overall, the simulation results indicated that plug-in hybrid and electric city buses have the best potential to reduce energy consumption and emissions. The study also concludes that the capital and energy storage system costs of city buses are the most critical factors for improving the cost-efficiency of these alternative city bus configurations. Furthermore, the operation schedule and route planning are important to take into account when selecting hybrid and electric city buses for fleet operation.

Another example of cost and benefits analysis in public bus transport context is presented in /18/ for New Zealand. The paper describes an approach to measuring transport externalities that are typically left unmeasured in fleet procurement decisions namely vehicle noise and emissions. It considers modern diesel bus, diesel/electric hybrid and fully electric options.

In conclusion this paper reflects upon the implications for transport agencies and bus operators. Improved evaluation methods suggest that upgrading urban bus fleets to hybrid or electric buses can bring significant long-term benefits.

Broadly similar analysis was also performed for Latvia in /19/. This latter paper discusses the possible economic effect on regional development by developing applicable methodology and analysing differences in costs, both operational costs and initial investments. The research shows, that within current state of affairs in Latvia, initial investments of changing public transportation fleet to electric buses and the costs of battery replacement still outweighs the monetary advantages gained from lower operational costs and additional environmental benefits.

6.6 Total costs of ownership

Total costs of ownership (TCO) is a financial estimate intended to help buyers and owners determine the direct and indirect costs of a product or a system. TCO analysis includes a variety of costs, e.g. material, manufacturing, distribution, operations etc., while it also considers incentives developed for an alternative approach. Incentives and other variables such as tax credits and even ecological economics, when it includes social costs.

A total costs of ownership (TCO) analysis was performed for electric urban bus system for Berlin in /20/. Basically, this study presented a technology assessment of battery-electric public bus systems based on technical and economical key performance indicators. The methodology was applied to an electric bus project for the city of Berlin to facilitate the selection of a suitable technology. For this pupose, a step-wise approach was applied. Firstly, an energetic simulation model was set up to forecast the needed energy for daily service based on bus operating profiles. Secondly, a pre-selection of potential electric bus solutions was made by qualitative evaluation of different systems using defined technical and economic indicators. Thirdly, a detailed comparison was made between the remaining technological alternatives taking monetary-based aspects into account. This economic analysis is conducted by means of a total cost of ownership (TCO) approach.

In conclusion, the study revealed that under Berlin conditions inductive opportunity charging technology fulfils the comprehensive system’s requirements and shows relatively low TCO values.

6.7 Other studies

Several other recent studies referring to analysis of electric or other alternative bus technologies are presented in /21/, /22/, /23/, /24/, /25/, /26/, /27/. However, they do not use any particular method in the analysis, but can otherwise be taken as worthy examples of such analysis.

7. CONCLUSIONS AND RECOMMENDATIONS

Electric buses propose a lucrative option for future urban bus transport: zero emissions while driving, and full use of sustainable and renewable energy (low-carbon/carbon-free electricity). Apart from the environmental benefits, eBuses have many features that can make bus transport more appealing to the users.

However, electric buses are still in the early stages of their development, and especially the electric energy storage needs improvement in terms of cost and capacity. Furthermore, the infrastructure needed to supply and charge the electricity that the eBuses use, is another technology in development phase, even if public transport vehicles have been operating with electricity for over a century, but those (trams, metro, trolleys) have all been using direct and constant contact to the grid via catenary wires.

Electric buses and the charging infrastructure form a system rather than a product, and thus procurement of public transport services by electric buses is somewhat more complicated than procurement of bus services by regular ICE-driven buses. Especially challenging this becomes, when an opportunity-type of charging system is chosen, because then the charging hardware is to be placed in cityscape, outside the bus operators own premises (depot). Also the diversity of the technical solutions poses a challenge to make right choices, as the chosen architecture will lock the future development, as interoperability between systems is nearly nonexistent. Standardisation efforts have begun, and ZeEUS project has been an instrumental actor in advancing this work.

Key Performance Indicators (KPI) are widely used to monitor performance of business, but also other processes, and in ZeEUS, this methodology has been successfully use in evaluating the achievements of the demonstrations that formed ZeEUS.

When using and selecting KPIs in procuring and contracting electric buses of bus services, one has to be very careful. To make right choices, one must understand the innards of a complex system and know “what drives what”, because if a high-level KPI is used as metrics for service quality, one must always make sure that the sources, where the data is coming from and paths of information that is feeding this KPI are known, and the party in charge has the possibility to monitor also the root sources and make necessary adjustments, if necessary.

In other words: if any high-level output-type KPI is used to monitor the quality of the service, the operator must have control of the driver-type, operational KPIs. If there are more parties involved, it is important to choose the right KPIs to use as “tokens” for measuring/monitoring the propagation of value added in the process thru the chain of operations.

A good system definition and selection of right indicators should already be part of the TOR, as then the bidders could see, how their product or service is valued and how the value is monitored, and this should lead to a design of an effective product or .procedure. However, we must also remember, that the way something is measured and monitored, will always influence the process: “you get what you ask for”. Therefore, the system definition and choice of indicators have a crucial role in the framework.

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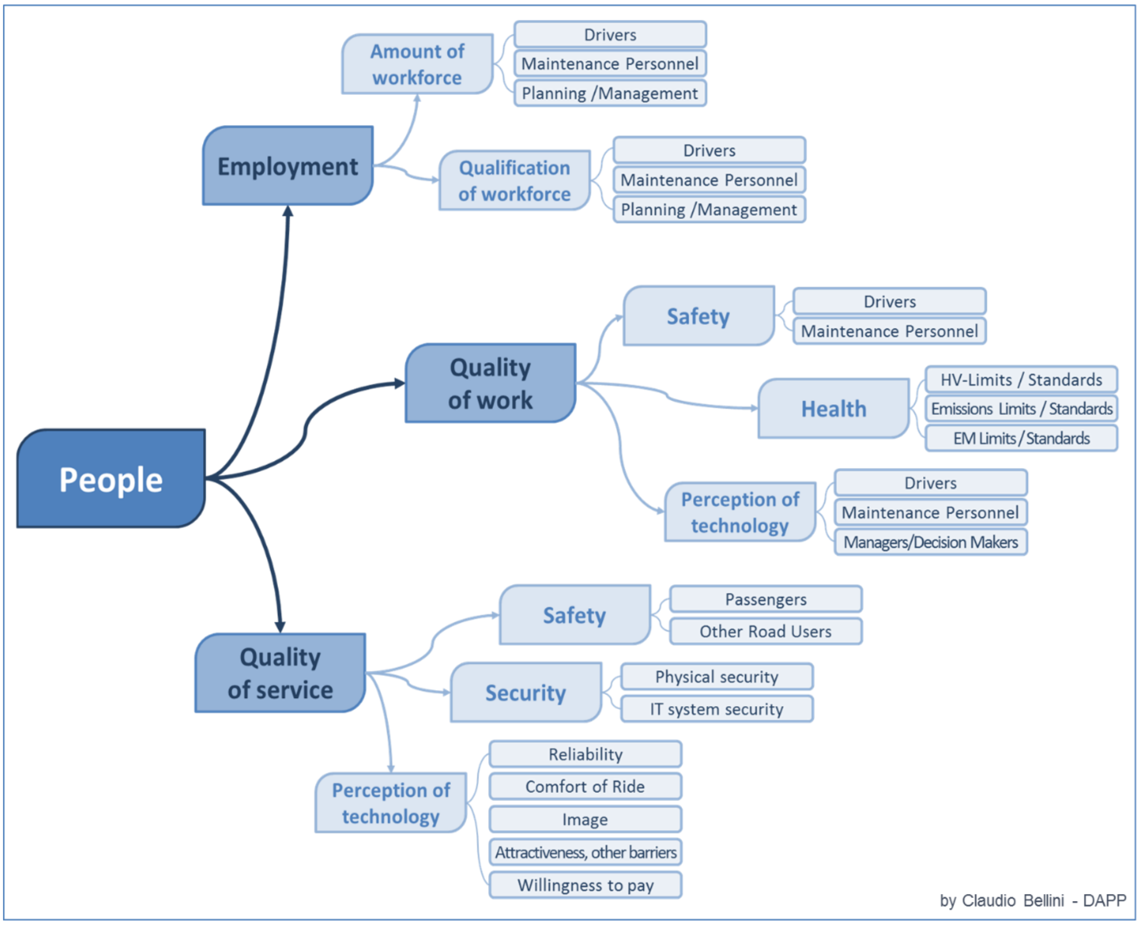
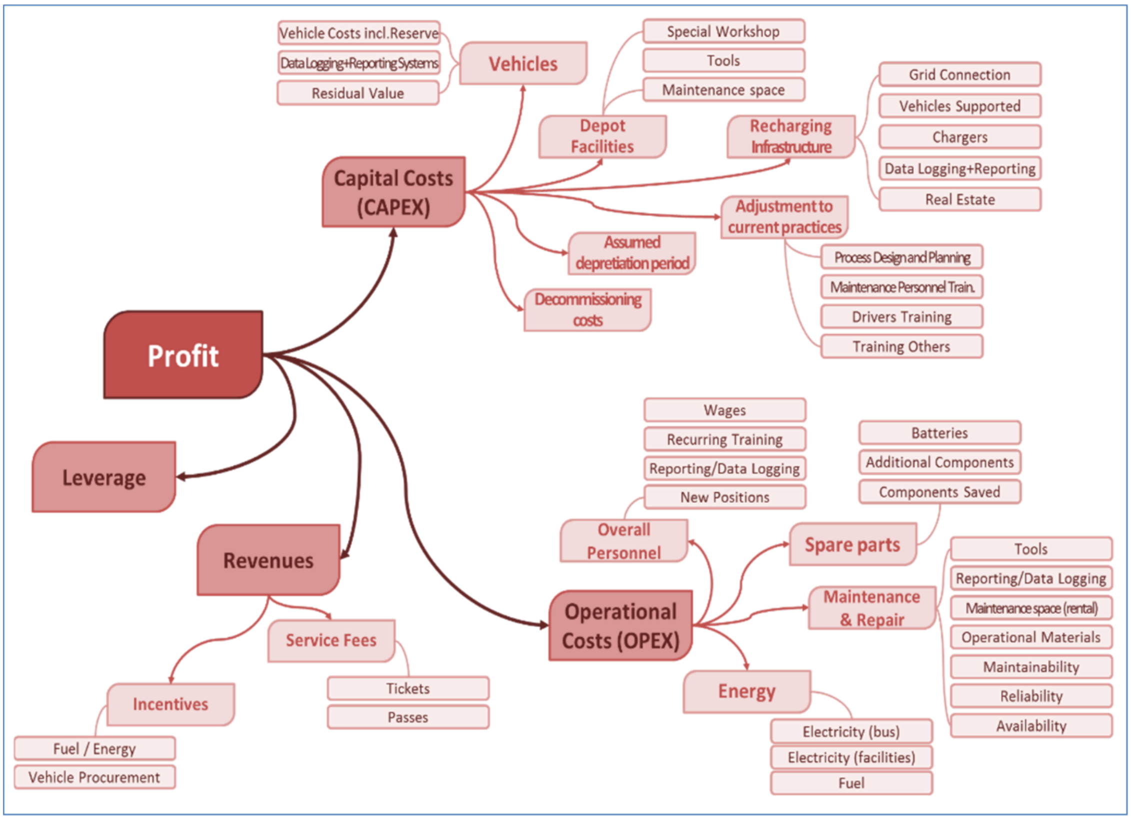
9. ANNEXES

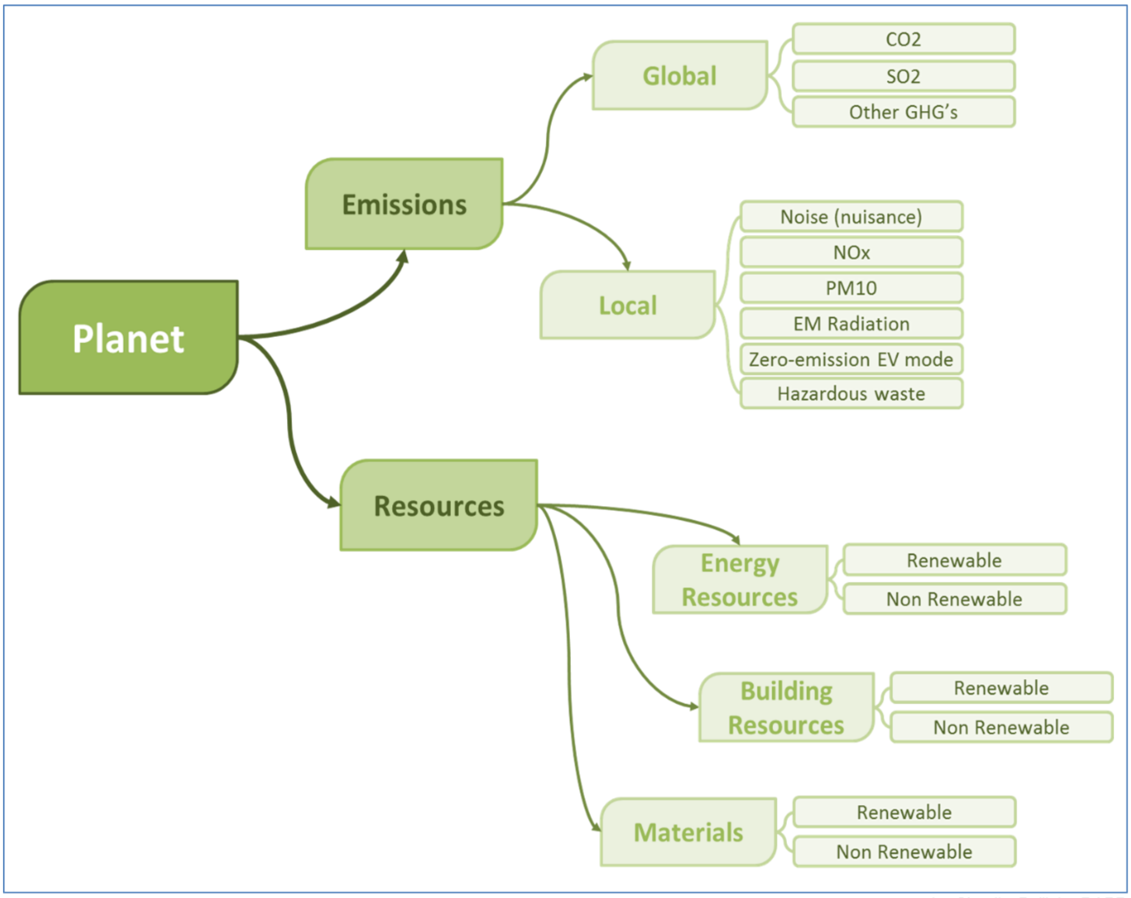
ANNEX 1



Roots, Branches and Sub-Brances for "PE" Bottom-Line



Roots, Branches and Sub-Brances for “PPROFIT” Bottom-Line



by Claudio Bellini - DAPP

Roots, Branches and Sub-Brances for "PLANET" Bottom-Line

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