FLIX

Feasibility Study E-Mobility

July 2024

FLIXBUS FLIXTRAIN Greyhound KÂMILKOÇ 1926

Feasibility Study Electric Mobility | Content

01 Analysis of charging infrastructure

- Status quo and outlook of public and private heavy-duty charging infrastructure in Germany

02 Analysis of operational costs for BEV

- Literature research on selected TCO components for battery electric coaches compared to Diesel

03 Route analyses and strategic ramp up

- Methodology to assess the feasibility of routes to be served by battery electric coaches and prioritization according to suitability
- Introduction to a tool for analyzing BEV feasibility in Flix's network

04 Financing and leasing models for xEV buses

- Industry examples of financing options for alternative drive vehicles
- Overview of industry approaches to residual value assessment

05 Economic and ecological impact of FT

- Optimization model to support the steering of the fleet transformation to alternative drives
- Scenario-based analysis of ecological and economic impact

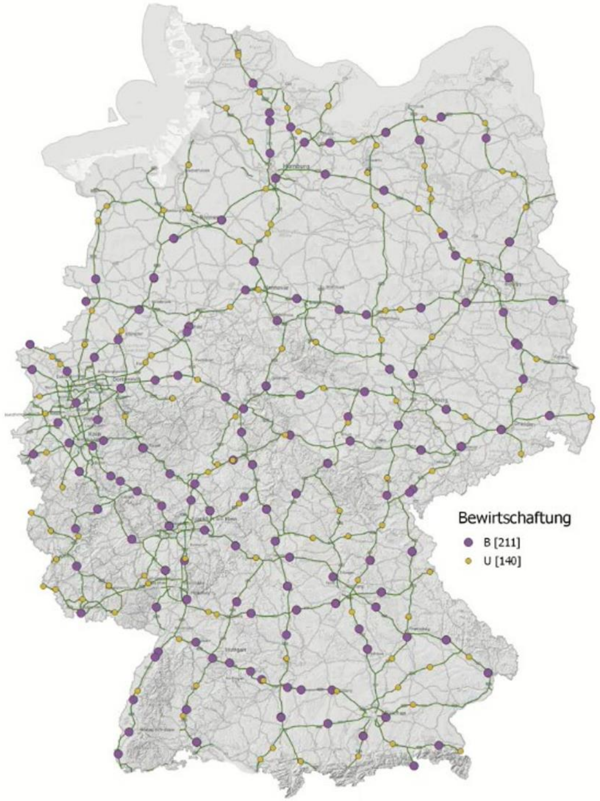
01 Analysis of Charging Infrastructure

The development of a public charging infrastructure network for heavy-duty vehicles is planned

Public charging infrastructure development

Germany

- **Heavy-duty charging infrastructure development** plans according to AFIR (along TENT-T core and network)[01]
- Focus only on **service stations** along highways
- Public HDV **charging close to stops** (mostly city centers) missing



Private charging infrastructure development (selection)

- Joint venture between **Daimler Truck, TRATON GROUP, and Volvo Group**
- Committed to build and operate **1,700 high-performance public charging points for heavy-duty vehicles** in Europe by 2027
- Start in **Germany, the Netherlands, France, Belgium, Spain, Italy, Norway and Sweden**

- Cooperation agreement for research on **mega watt charging**
- Besides trucks **also focus on coaches**, product expected in 2025

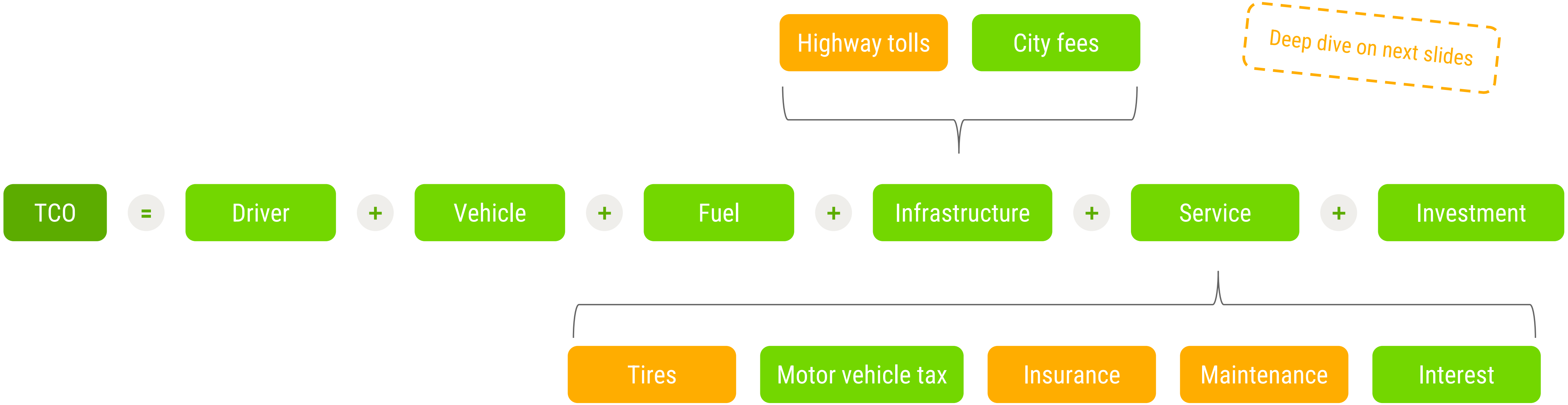
- ShellRecharge to **build truck charging infrastructure** along traffic hubs

[01] Alternative Fuels Infrastructure - European Commission (europa.eu)

02 BEV Operational Costs

With a currently higher vehicle price, the operational costs of BEVs are relevant to make BEVS economically attractive

Different alternative drive technologies can be compared by considering the TCO (Total Cost of Ownership), e.g. relative to Diesel. Due to low market availability of BEV coaches, trucks can provide a first reference.



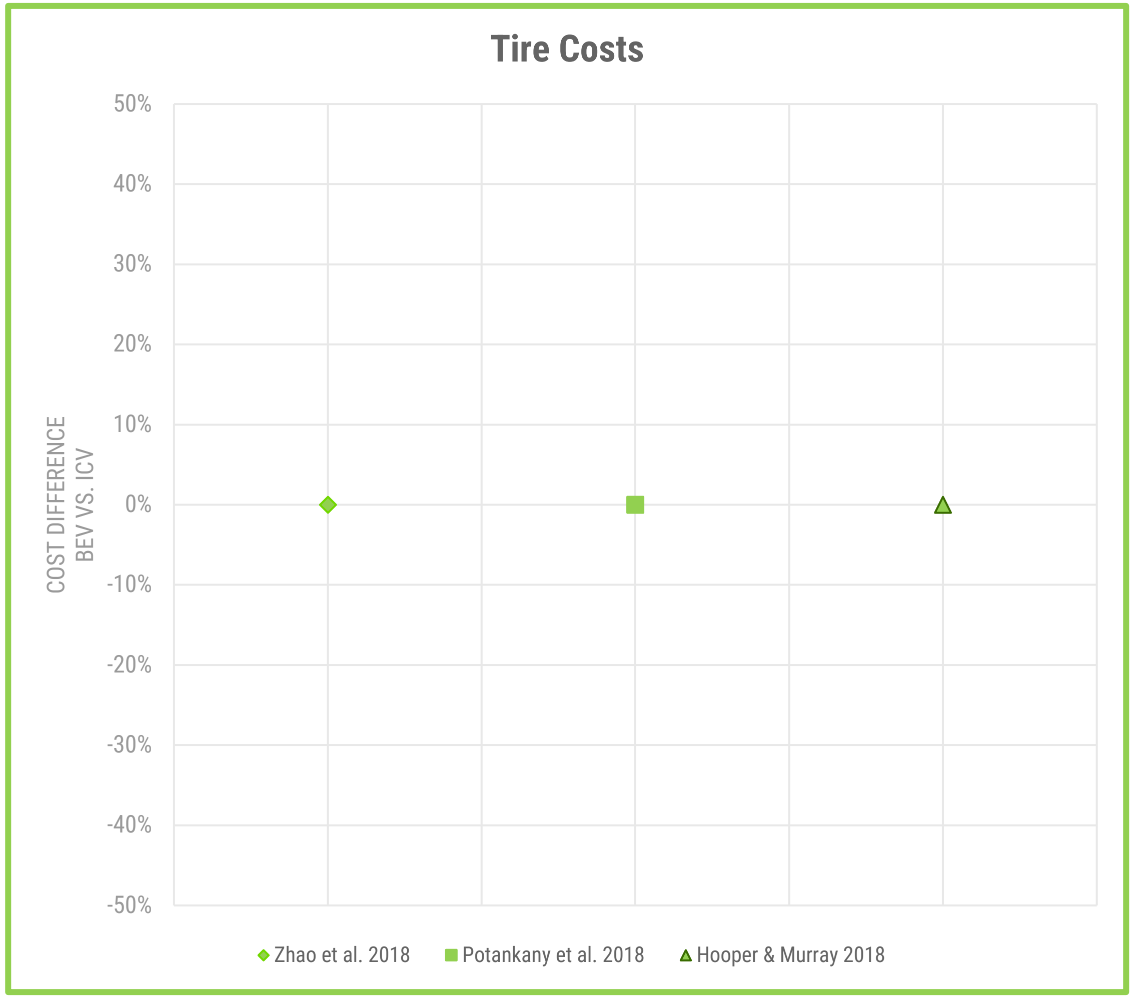
Literature assumes lower maintenance costs for BEV trucks compared to ICVs

Summary

- The literature examined assumes *maintenance costs* for BEV trucks to be **35% (± 9%) lower** than for ICVs
- Seven scientific papers were examined in the period 2018 – 2023. It should be noted that these papers considered **heavy-duty long-haul trucks**, but in some cases examined different geographical areas (e.g. exclusively EU or China)
- The trend that BEV trucks have lower maintenance costs is probably justified to the fact that battery electric vehicles have **significantly fewer individual components** compared to conventional technologies, thus saving labor and material costs [01]

[01] Wang, G., Miller, M., & Fulton, L. (2022). Estimating Maintenance and Repair Costs for Battery Electric and Fuel Cell Heavy Duty Trucks. UC Davis: Sustainable Freight Research Center

No differences were found for tire costs when comparing battery electric and conventional trucks

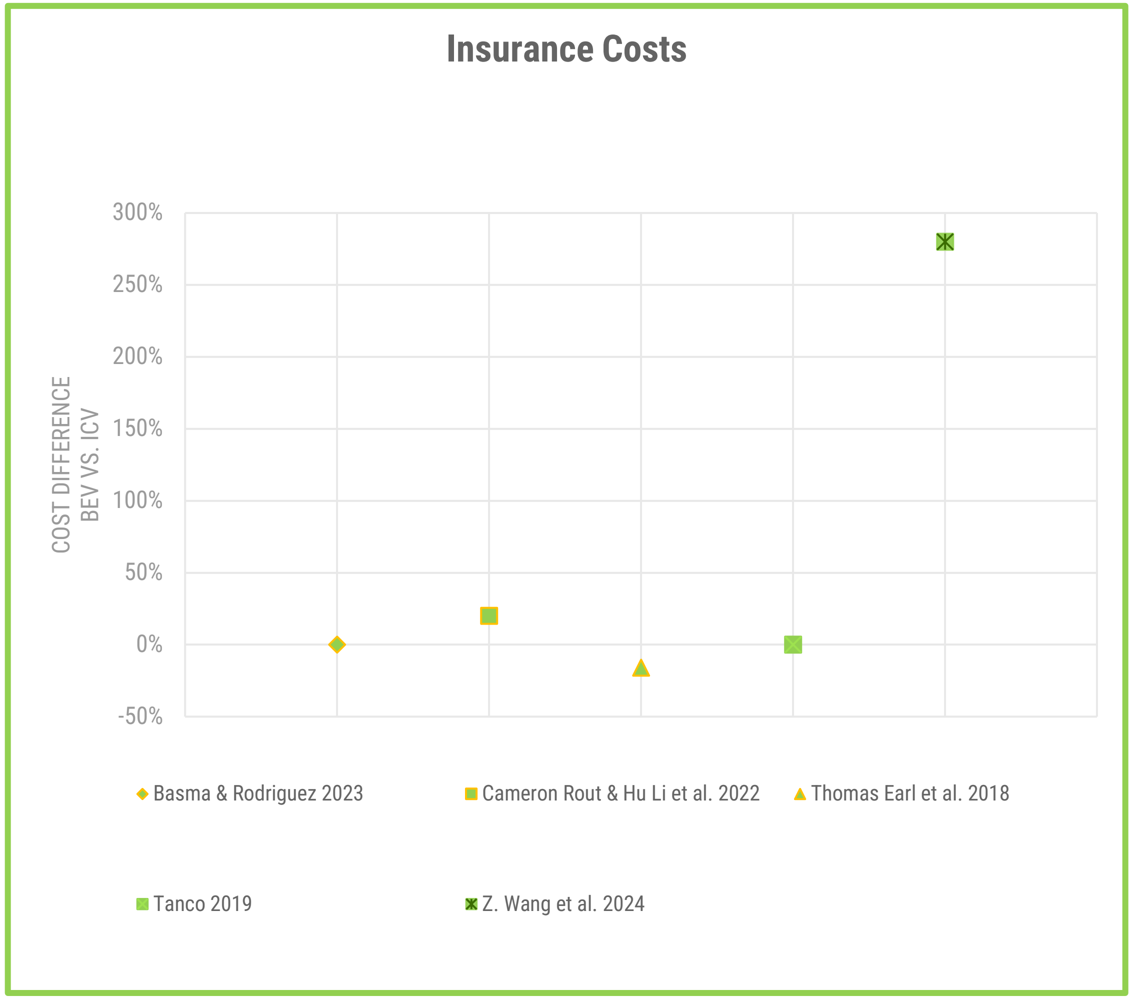


Summary

- The literature currently assumes that tire costs will **remain the same** for heavy duty trucks**.** This is the result of a study of three scientific papers in the period 2018 and 2021
- However, many papers did not consider tires **separately but included them as part of maintenance costs**
- One could assume that tires of BEV vehicles have to meet different requirements due to the higher load of battery-powered vehicles. However, it is argued that the higher weight due to the vehicle components is **negligible compared to the total weight of a fully loaded heavy duty truck**[01]

[01] Björn Nykvist & Olle Olsson (2021), *The feasibility of heavy battery electric trucks*, Joule Volume 5, Issue 4, Pages 901-913

» The current study status on insurance costs is indifferent



Summary

- The result for insurance costs is **ambiguous**. There is a slight trend in which the insurance costs for BEV trucks **appear to be more expensive**.
- However, there are also papers that assume **price parity or even lower** insurance costs.
- Possible reasons: Different assumptions on resale price, maintenance costs, reusability of technical components, different global regions examined.
- Practical Recommendation: "(...)it is generally believed that insurance premiums for electric HGVs are linked directly to the cost of vehicle repairs and component replacements. Most existing TCO studies (Basma et al., 2021; Mao et al., 2021; Rout et al., 2022) determine insurance costs by assuming fixed proportions of vehicle purchase prices across technologies." [01]

[01] Z. Wang et al. 2024, *A total cost of ownership analysis of zero emission powertrain solutions for heavy goods vehicle sector*, Journal of Cleaner Production

FLIX

Austria is the only country among the focus countries with influential discounts on tolls for ZEV Buses

Country	Tolling scheme	EURO VI	ZEV	Difference	
Germany	No road tolls	-	-		-
Czech Republic	Distance based, dependent on road type	0,031 € /km[01]	0,028 €/km[01]	**-10 %**	**-0,003 €/km**
Slovakia	Distance based, dependent on road type	0,055 € /km[01, 02]		0 %	0,000 €/km
Portugal	**Concession contracts:** Distance based, but no fixed km charge	0,170 € /km[01, 03]		0 %	0,000 €/km
Austria	Distance based for main highways, fixed fee for special roads (example: passes)	0,346 € /km[01]	0,086 €/km[01]	**-75 %**	**-0,260 €/km**
Sweden	Buses are exempt	-	-	-	-
France	**Concession Scheme**, renewal expected 2030 Distance based, but no fixed km charge	0,328 € /km[01, 03]		0 %	0,000 €/km
Belgium	Buses are exempt[4]	-	-	-	-

Calculation example: >14 t bus with 3 axles

[01] Average of road types, based on focus routes and/or assumption based on distribution of road types in general road network [02] no difference between EURO VI and ZEV [03] no difference between fuel type or EURO class at all [04] except for Liefkenshoektunnel

03 Route analyses and strategic ramp up

An analytical categorization that considers various technological and timetable-specific parameters support in route prioritization for BEV

Two metrics were developed as part of the prioritization process:

1. Electrification Category

The electrification category is assigned to each *unique line* and gives an indication on how easily a battery electric bus with the defined technical parameters can serve this unique line. There are three categories defined as follows

Category 1: Bus can serve a **roundtrip** (a ride from A to B and B to A) with one charge at A (or B), so charging infrastructure is required at either A or B OR

bus can serve the **single ride** A to B and the pause time at B is long enough to charge the required electricity for the return ride B to A, so charging infrastructure is required at both A and B

Category 2: Bus can serve the single ride A to B, but the pause time at B is not long enough to charge the required electricity for the return ride B to A.

Category 3: Electric battery bus can not serve the single ride from A to B.

2. Line Feasibility Score

Average electrification category of a line, weighted by the number of annual trips per electrification category.

$$\textbf{line feasibility score}_{L} = \frac{\sum_{UL \epsilon L} \text{electrification category}_{UL} * \text{number of rides}_{UL}}{\sum_{UL \epsilon L} \text{number of rides}_{UL}}$$

with L = Line, UL = Unique Line

Definitions of terms used:

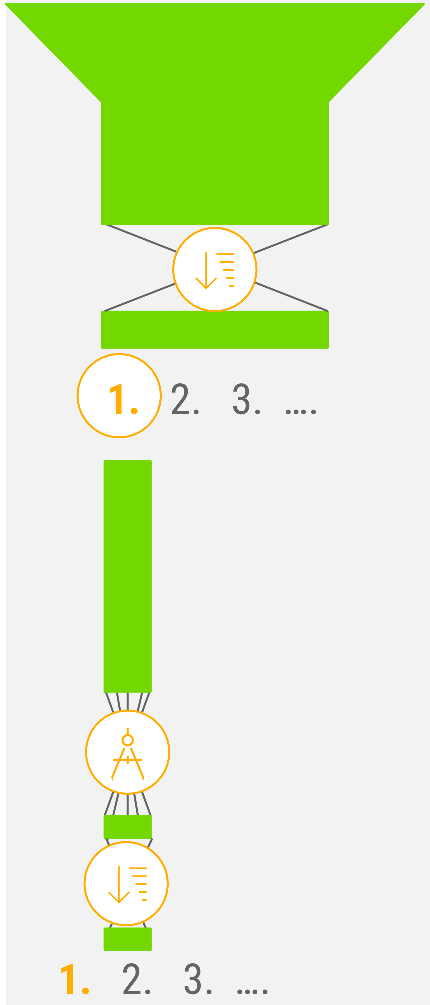
Rides refer to single trips between a start and end station of a line (**A to B**).

A ***line*** summarizes multiple rides between two stations in the annual plan. It usually operates between the same two stations (**A to B and B to A**), but in the case of open jaw routes can also operate between several stations.

The operational parameters (e.g. distance and pause time) of one ride of a line may differ throughout the annual plan. A ***unique line*** is a specific combination of distance and pause time which can occur in one or multiple rides of the line. **One line number therefore entails multiple unique lines**.

The Line Feasibility Score is used to prioritize lines and stations

1. Find optimal lines: Filter lines by
   - Prio 1: Line feasibility score =1.0 (i.e., all unique lines have electrification category = 1)
2. Sort/prioritize stations by number of lines per End Station
3. Analyze lines of chosen End station:
   - Analyze if charging is required at the end station only, or also at the start station (bus cannot make return trip on one charge)
   - Check for other 1.0 Feasibility Score Lines to/from Start Station
   - Determine Overlap at End and Start Station if only this line was running
   - Analyze Start Station type and infrastructure
   - Check Start Station Surroundings for possible charging locations
4. Test Scenarios:
   - Combine lines that go to chosen End Station
   - Determine yearly rides per year per overlaps at End station
   - Prioritize



Start with all lines

Step 1. Lines with feasibility score = 1.0

Step 2. Lines with feasibility score = 1.0, *sorted by lines per End station*

Step 3. Perform further analysis based on various metrics, *e.g. convertibility of single/round trip; number of overlaps on start/end station; infrastructure situation etc.*

Step 4. Lines with feasibility score = 1.0, sorted by lines per End station, *ranked by combinations with most rides/year/overlaps at End Station*

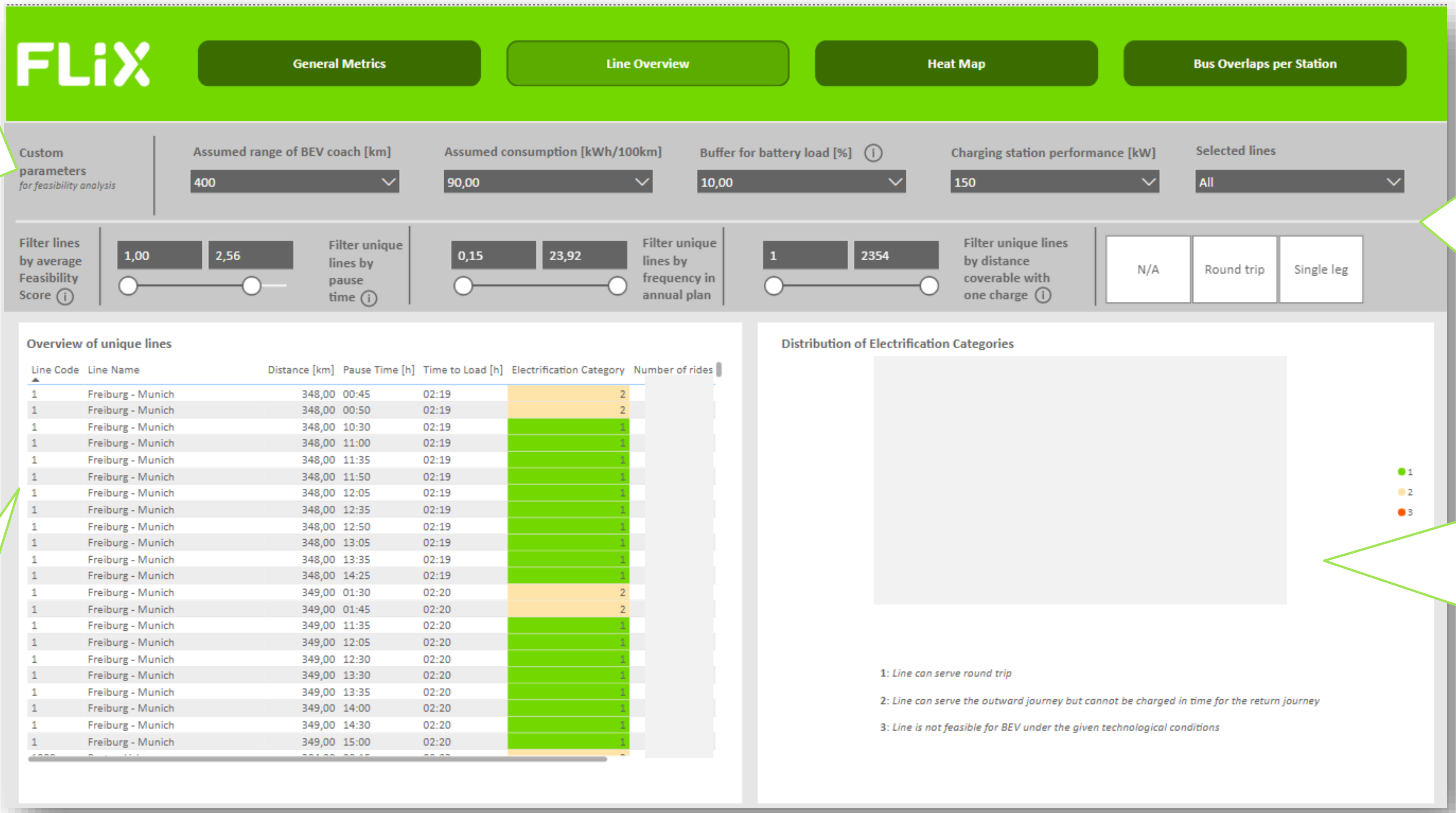
In an interactive dashboard tool, the feasibility of lines for BEV – given different technology assumptions – can be analysed

Assumed technology parameters

- Assumptions were made about the parameters of the feasibility analysis
- These parameters are used for the calculation of proposed metrics

Line prioritization

- Based on the technological parameters & timetable information, a metric for the prioritization of lines was developed



Line Code	Line Name	Distance [km]	Pause Time [h]	Time to Load [h]	Electrification Category	Number of rides
1	Freiburg - Munich	348,00	00:45	02:19	2	
1	Freiburg - Munich	348,00	00:50	02:19	2	
1	Freiburg - Munich	348,00	10:30	02:19	1	
1	Freiburg - Munich	348,00	11:00	02:19	1	
1	Freiburg - Munich	348,00	11:35	02:19	1	
1	Freiburg - Munich	348,00	11:50	02:19	1	
1	Freiburg - Munich	348,00	12:05	02:19	1	
1	Freiburg - Munich	348,00	12:35	02:19	1	
1	Freiburg - Munich	348,00	12:50	02:19	1	
1	Freiburg - Munich	348,00	13:05	02:19	1	
1	Freiburg - Munich	348,00	13:35	02:19	1	
1	Freiburg - Munich	348,00	14:25	02:19	1	
1	Freiburg - Munich	349,00	01:30	02:20	2	
1	Freiburg - Munich	349,00	01:45	02:20	2	
1	Freiburg - Munich	349,00	11:35	02:20	1	
1	Freiburg - Munich	349,00	12:05	02:20	1	
1	Freiburg - Munich	349,00	12:30	02:20	1	
1	Freiburg - Munich	349,00	13:30	02:20	1	
1	Freiburg - Munich	349,00	13:35	02:20	1	
1	Freiburg - Munich	349,00	14:00	02:20	1	
1	Freiburg - Munich	349,00	14:30	02:20	1	
1	Freiburg - Munich	349,00	15:00	02:20	1	

Filter selection

- Users can apply various filters, both schedule-specific variables and designed metrics created to quantify prioritization

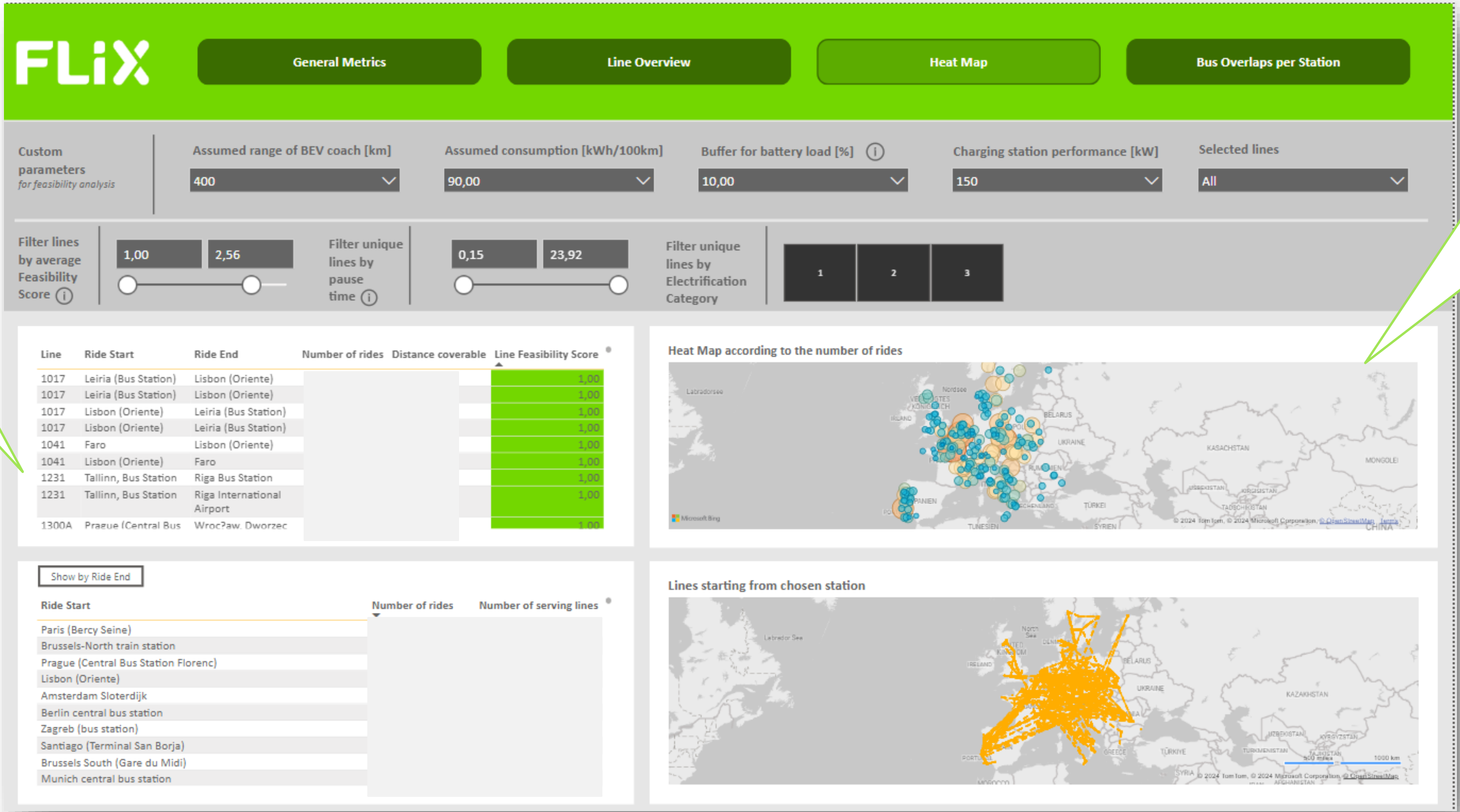
Overview of (non-) transformable lines

- Timetable-specific overview of the transformability of the lines based on the user's filters/ assumptions

Bus stations with a high amount of lines that are suitable for BEV can be prioritized for the installation of charging infrastructure

Deriving station prioritization from bus frequency & line feasibility

- Prioritization of stations based on timetable information and suggested metrics



Heat map view

- Graphic visualization for the identification of hotspots in the global network
- Graphic elements can be used for further analyses or for filtering

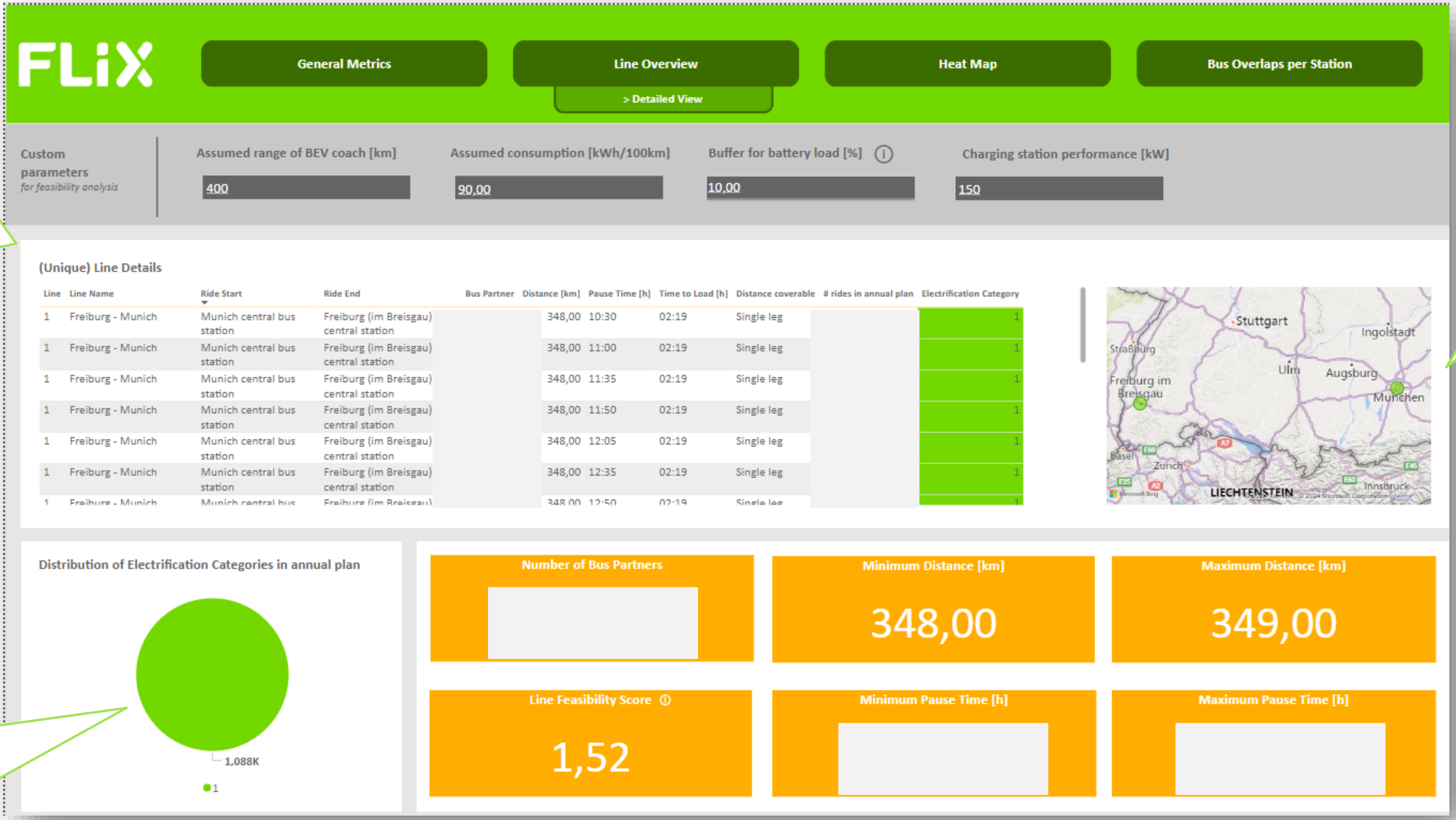
Drill-down functions enable further insights to core metrics of single lines

Detailed view of line variations

- Detailed view for selected route with information on feasibility, frequency and timetable-specific data

Overview of key metrics

- Summary of feasibility-relevant metrics from the timetable for the selected line



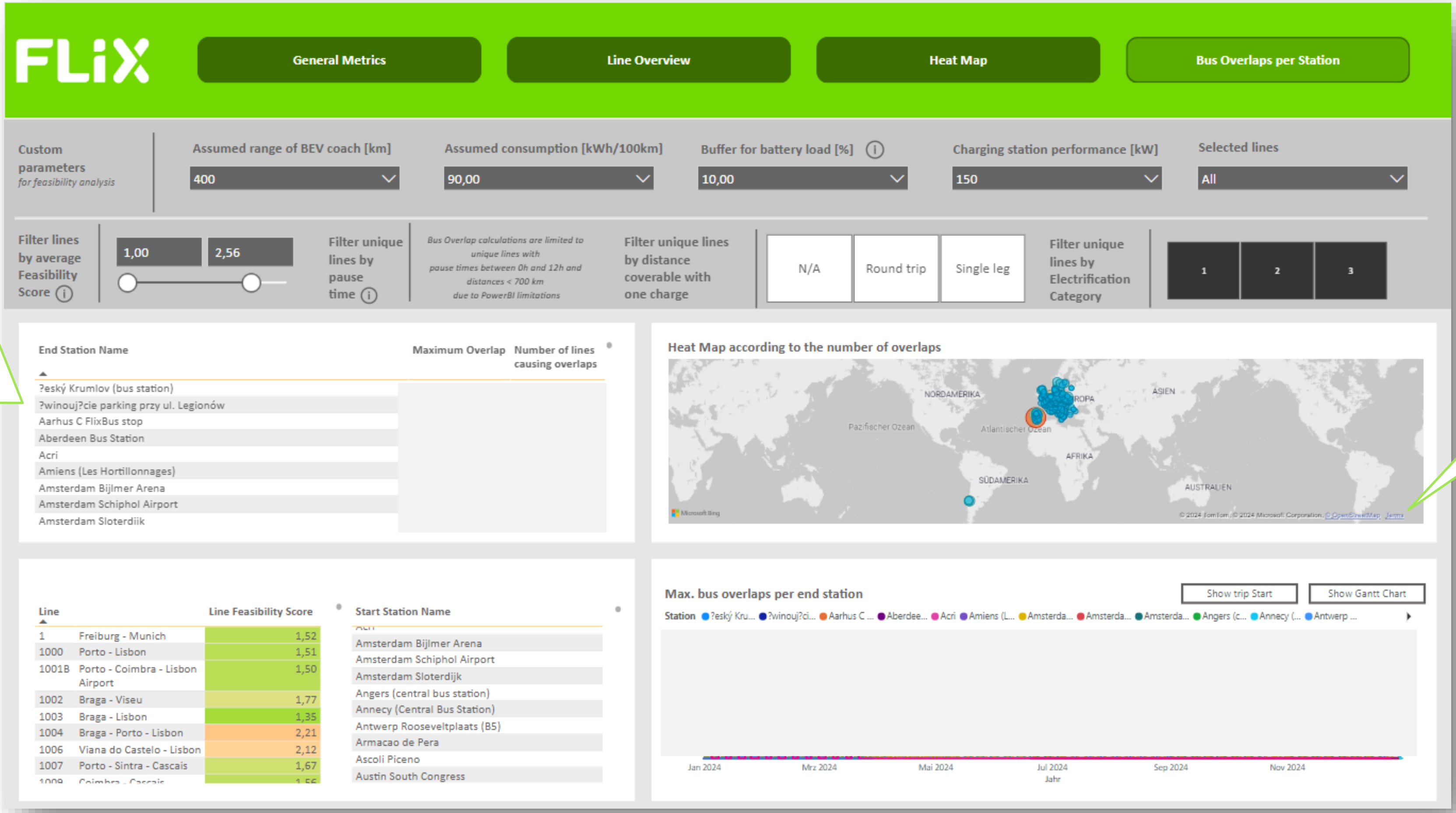
Line	Line Name	Ride Start	Ride End	Bus Partner	Distance [km]	Pause Time [h]	Time to Load [h]	Distance coverable	# rides in annual plan	Electrification Category
1	Freiburg - Munich	Munich central bus station	Freiburg (im Breisgau) central station		348,00	10:30	02:19	Single leg		1
1	Freiburg - Munich	Munich central bus station	Freiburg (im Breisgau) central station		348,00	11:00	02:19	Single leg		1
1	Freiburg - Munich	Munich central bus station	Freiburg (im Breisgau) central station		348,00	11:35	02:19	Single leg		1
1	Freiburg - Munich	Munich central bus station	Freiburg (im Breisgau) central station		348,00	11:50	02:19	Single leg		1
1	Freiburg - Munich	Munich central bus station	Freiburg (im Breisgau) central station		348,00	12:05	02:19	Single leg		1
1	Freiburg - Munich	Munich central bus station	Freiburg (im Breisgau) central station		348,00	12:35	02:19	Single leg		1
1	Freiburg - Munich	Munich central bus	Freiburg (im Breisgau)		348,00	12:50	02:19	Single leg		1

Graphical representation of the start and end points

An overlap analysis is used to determine the need for infrastructure at start and end stations

Quantifying the need for charging stations per start/end point

- Analysis of the maximum number of overlaps per station
- This can be used to quantify the precise requirements for the charging station infrastructure



Identification of agglomerations in bus network

- Graphical visualization of the overlap distribution in the network and its development over time

Deep Dive: Three European metropolitan areas and their exemplary routes according to the proposed approach model [1]

Berlin Central Station

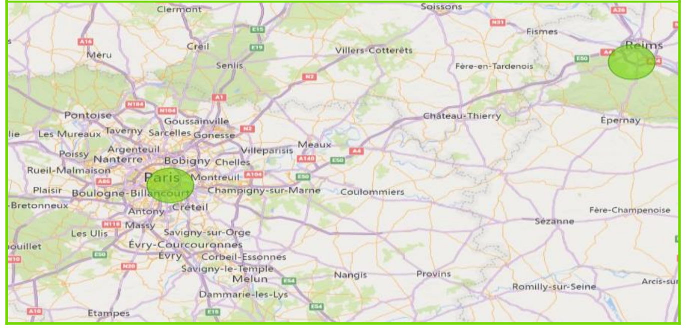
Single Trip: Berlin – Dresden
Distance: 199 – 200 km
Pause Time: 2:10 – 8:25 H

Round Trip: Berlin – Leipzig
Distance: 180 km
Pause Time: 1:05 – 23:20 H

Paris Bercy Seine

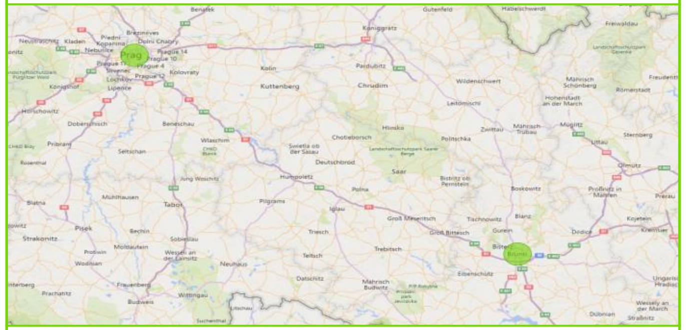
Single Trip: Paris – Brussels
Distance: 311 – 318 km
Pause Time: 2:15 – 14:15 H

Round Trip: Paris – Reims
Distance: 145 km
Pause Time: 0:55 – 12:40 H



Prague Central Station

Single Trip: Prague – Brno
Distance: 209 – 244 km
Pause Time: 1:40 – 18:35 H



Round Trip: Prague – Karlovy Vary
Distance: 129 – 179 km
Pause Time: 0:30 – 19:30 H

[1] Analysis was conducted for the following setup: Assumed range = 400km; assumed consumption = 90 kWh/100km; buffer for battery load = 10%; charging station performance = 150 kW

FLIX

04 Financing and leasing models for xEV buses

The analysis of financing options is split into two main components

The introduction of alternative drive technologies leads to new opportunities and risks for companies in the transportation industry. These include financial uncertainties. In particular, these are due to

1. small number of OEMs / low market availability
2. high initial purchase prices and consequently leasing costs
3. lack of experience in estimating residual vehicle values and thus very conservative assessments.

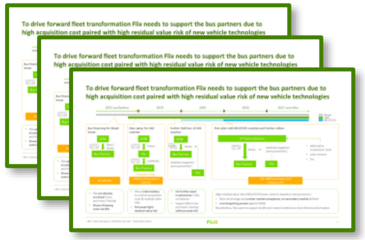
These risks can be countered by looking at other industry examples in order to design new financing models and develop approaches for determining residual vehicle values.

Industry Examples

Consideration of case studies from an OEM perspective and the logistics industry

Residual Value Analysis

Industry examples for residual value assessment and mitigation strategies / risk sharing



OEMs are designing holistic models for the roll-out of BEV and FCEV trucks as part of various projects

	Hyundai	IVECO	Shell	Voltra Trucks
	JV / Pay-per-use	Partnership / Rental platform	Pay-per-use / Partnership	TaaS
Model	Hyundai conducts a project in Switzerland to establish a fleet of 1,600 XCIENT Fuel Cell H2 trucks by 2025 together with **H2 Energy AG** trough a **JV** (Hyundai Hydrogen Mobility) and a **pay-per-use-model**.[1]	IVECO, started a partnership with **Nikola**, manufacturer of fuel-cells, through a joint venture. Nikola is collaborating with **E.ON** to offer a holistic solution for hydrogen fuel supply.[4]	Shell has introduced a full service pay-per-use model for hydrogen trucks in cooperation with "Paul Nutzfahrzeuge", where customers pay a monthly rate based on the distance traveled.[7]	Volta Trucks adopted a full-service-TaaS model, offering customers electric trucks and extras (charging infrastructure, infrastructure etc.) for a fixed monthly fee.
Opps & Risks	• Global expansion plans[9] • Hydrogen production and infrastructure are included • **Fluctuating energy prices and the availability of green hydrogen are potential risks**[2]	• IVECO plans to establish **the rental platform GATE to facilitate easier access to their trucks**[5] • Collaboration of three well-known players • The partnership experienced delays, indicating **challenges in collaboration**[6]	• Holistic approach **to address cost and risk concerns** of customers[8] • **Distribution of hydrogen** still unclear	• Holistic solution • Minimal risks due **to 3-months-payment-system** • **High dependency** on external battery supplier • Only for short-haul-trucks (<200km) available

[1] hyundai.news, [2] cargo-jounral.org, [3] electrive.com, [4] ecomento.de, [5] ivecogroup.org, [6] seekingalpha.com
[7] shell.de, [8] electrive.net, [9] reuters.com

Electric and hydrogen powered trucks are already part of major logistics companies' fleet transformation

	DACHSER	UPS	DHL
	JV / Pay-per-use	Partnership OEM	Pilot projects / Public funding
Model	DACHSER aims to transfer its fleet with 50 BEV trucks and tests hydrogen powered TaaS in parallel (H2 Green Power).[01, 02] Additionally, it invests in its own charging infrastructure where electricity is produced by its own photovoltaic systems.[01]	UPS acquired a minority stake in Arrival and committed to purchasing 10,000 custom-built electric delivery vehicles, fostering a partnership for developing advanced, sustainable vehicle technologies.[03]	DHL has initiated a **pilot project with a hydrogen-powered heavy-duty vehicle** and is concurrently investing in the electrification of its fleet to develop and test sustainable and low-emission transportation solutions in logistics with a scientific partnership (i.e. HyCET).[04] **13 new battery electric trucks** (Volvo FL Electric 4x2) incl. required infrastructure were funded by the Ministry of Digital and Transport with in total 2.3 million (KsNI)[05]
Opps & Risks	• Low invest.-costs through VaaS • Multiple OEMs possible • Only one hydrogen station to refuel bus • High investment-costs for BEV trucks incl. infrastructure	• **Direct influence** on truck configuration • New market • Only 1 OEM and high financial investment costs	• Less risks via pilot projects. • Research project could enable further insights to hydrogen infrastructure • Fuel procurement to be clarified • High investment costs assumed if both, fuel infrastructure and vehicle, are financed by DHL

[01] dachser.de, [02] dachser.de, [03] ups.com, [04] dhl.com , [05] https://group.dhl.com/content/dam/deutschepostdhl/de/media-relations/press-releases/2023/pm-e-lkw-berlin-20230713.pdf

Residual value assessment | There are four instruments to estimating residual value curves frequently applied in industry

	Modeling from historic sales data	Expert estimation	Top-Down Approach: Conservative estimates	Bottom-Up Approach
Description	Analysis of sales data and price trends of vehicle.	Assessment by professionals with specific knowledge about electric vehicles.	Use of depreciation curves from similar vehicles with different technology as a reference.	Valuation based on the analysis of individual components of the vehicle.
Example	Evaluation of price development for electric buses over the past years, based on actual sales data.	A vehicle appraiser[01] evaluates the residual value based on condition, technology, market acceptance, and comparison with similar vehicles.	Adapting depreciation curves of diesel buses to make estimates for BEV buses, considering differences in e.g., operational and maintenance costs.	Separate valuation of the chassis and battery of the electric bus, considering their respective lifespans and amortization rates.
Challenges & Limitations	• **Limited historical data** due to the relative newness of electric buses • **Rapid technological advancements** can quickly render historical data outdated	• Subjective Perception: The inherent subjectivity in expert assessments can lead to **inconsistent and biased valuations** due to individual differences in experience • Consulting several experts can be **costly**	• Electric trucks may **significantly differ** in key aspects like technology and maintenance from diesel trucks, limiting the accuracy of this method • Difficulty in **quantifying a suitable conservatism margin**	• Complexity in valuing individual components • Challenges in assessing the **inter-action and combined value** of parts • Rapid technological progress can complicate the valuation of components like batteries

[01] e.g. Bähr & Fess

Separating the vehicle into main components enables a detailed view, however weighting the parts to derive a total value is complex

Chassis Value

Assumptions:

- The chassis value of a BEV bus is **proportional to the value depreciation** of a diesel bus
- The depreciation curve of a diesel bus can be taken from historic data, e.g. the **official Afa data**[01]
- The **market value corresponds to the book value** (i.e. conservative approach)
- According to Afa, the depreciation period of a passenger bus is nine years, i.e. **it has no residual book value after nine years**[01]
- Depreciation is calculated using the **linear method**[02]

* w_1, w_2 = Weighting of the components, V_0 = Initial value of chassis; d = Depreciation rate; C_0 = Initial capacity of battery; α= Degradation factor; n = Number of charging cycles per year

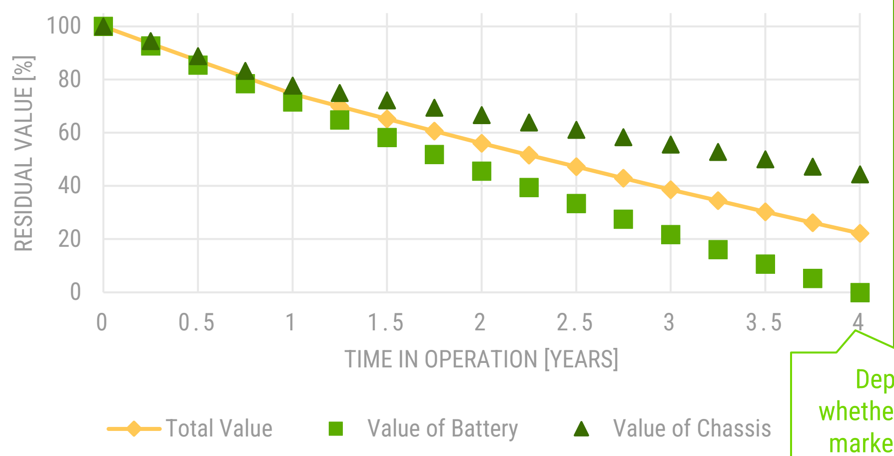
Exemplary simple model:

More advanced models can differentiate between further components, e.g. electric engines

$$RV(t) = w_1 * Value_{Chassis} + w_2 * Value_{Battery}$$
$$= w_1(V_0 - d * t) + w_2(C_0 * e^{-\alpha\, n * t})$$

At present, the energy storage costs of an electric truck account for up to 60% of the total production costs, although it is assumed that this proportion will decrease over time. [03, 04] **This model assumes an average of 50%.**

50% of total value → **BEV-Bus Value** ← 50% of total value



Depending on whether a secondary market is available

Battery Value

Assumptions:

- Battery value is **proportional to remaining lifetime** of battery
- A battery **undergoes degradation through the charging cycle** and loses residual life/value
- A battery is considered unusable if the capacity drops **below X%** of the initial capacity[05]
- Max. lifetime of battery is **XXX km** and a bus drives an average of **YYY km** per year[06]
- A bus has an **average range of X km** and is in **operation Y days/year** (2 charging cycles/day)
- The battery capacity can be estimated with a **linear or exponential function** within a degeneration model[07]

[01]Afa-Tabelle, [02]studyflix.de, [03]theicct.org, [04]ecomento.de, [05] fraunhofer.de, [06] Information adopted from expert's interview, [7]fva.net

FLiX

05 Economic and ecological impact of fleet transformation

An optimization model supports the strategic planning for the optimal fleet transformation to low- and zero emission buses

Motivation

Status Quo

- A **fleet transformation plan** that is economically efficient and aligned with the **emission target(s)** needs to be developed

Proposed solution

- Development of an **optimization model** to **support steering and determine the optimal fleet transformation** under given constraints
- **Results visualization** that enables advanced analyses, e.g.
  - Derive decisions for / against the use of certain technologies
  - Conduct **scenario analyses** with different assumptions on TCO / emissions to assess risk

User input

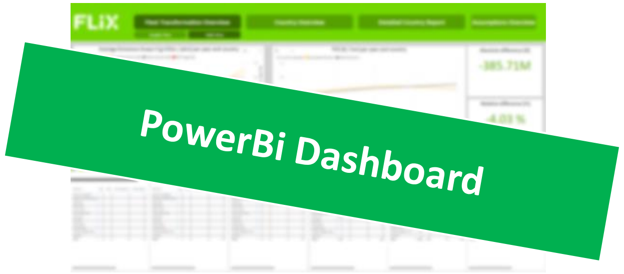
Fleet assumptions

- Market development
- TCO[01] and emissions assumptions

Constraints

- Climate target(s)
- Market availability and maximum tech share
- Limited TCO increase
- Step-wise ramp-up of new technologies

Optimizer:
Most cost-efficient fleet transformation for the considered BUs and timeframe compliant with the climate targets



Vision

Advanced interactive tool

- Optimization and visualization combined in a single connected tool with automated pipelines
- Holistic solution complemented by further applications, e.g. sustainability reporting (EU taxonomy etc.)

[01] TCO calculation includes vehicle costs, fuel costs and service costs (tires, motor vehicle tax, insurance, maintenance, interest) only.

Optimization model | Overview target function and constraints

Target function

Optimization problem (MILP)
Minimize:

> *Technical implementation using PuLP and the open-source solver CBC (COIN-OR branch and cut)[2]*

$$Z = \sum_c \sum_d \sum_t \{N_{c,d,t} * k_c * TCO_{c,d,t}\}$$

(Total fleet TCO[1] over transformation period in selected countries C)

Decision variables: $N_{c,d,t}$ number of buses per year t, country c and technology d

where:

c country, $c \in C = \{DE, IT, FR, \ldots\}$
d drivetrain technology, $d \in D = \{FCEV, BEV, \ldots\}$
t year, $t \in T = \{0, \ldots, y\}$ where $t = 0$ corresponds to the starting year
N number of buses
k_c kilometers per bus per year per country
$TCO_{c,d,t}$ total cost of ownership in [€/km] per country, tech and year

Constraints

Bus fleet development

Total number of buses per year and country

Determined total number of buses per year and country (derived from LTP bus km forecast and assumed annual kilometers per bus per country)

Bus lifetime / retiring

Bus retirement given assumed lifetime per technology and country

Emission targets

Climate targets

Maximum average fleet emission intensity (in gCO_2eq / pkm) per year

Costs assumptions

Maximum TCO increase in comparison to the diesel TCO

Per country, maximum increase of average fleet TCO in country compared to Diesel TCO in specific country

Limited year-on-year average TCO increase

Percentage increase in total fleet TCO costs year-on-year

Technology assumptions

Technology availability

Year from which on the technology is available in a country

Maximum share of drivetrain technology

Maximum fleet share that can be served by a certain technology, e.g. to depict limited charging infrastructure

Limited ramp-up for new technologies

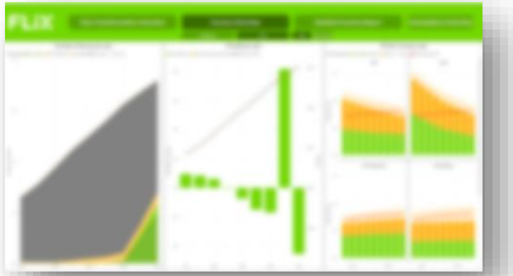
Limited number of bus purchases in the years after the introduction of a new technology

[01] TCO calculation includes vehicle costs, fuel costs and service costs (tires, motor vehicle tax, insurance, maintenance, interest) only. [02] https://coin-or.github.io/pulp/main/index.html

The dashboard visualizes the results for the optimized fleet transformation as well as the underlying data and model assumptions

Fleet Transformation Overview

- Provides an overview of the most important key figures resulting from the optimization, i.e. fleet, TCO[1] and emission development over the course of the optimization frame



Country Overview

- Summary of results and assumptions for both TCO[1] and emission
- Enables overall fleet and country specific figures

Detailed Country Report

- In-depth analysis on country level including all assumptions and results for the selected country

Assumptions Overview

- High-level summary of the optimization model and list of given constraints

[1] TCO calculation includes vehicle costs, fuel costs and service costs (tires, motor vehicle tax, insurance, maintenance, interest) only.

The Fleet Transformation Overview provides insights into the most important optimization results

Scope 3 Emission Tracking

- Overview of the development of various key figures on emissions
- **The fitted SBTi emissions trajectory** (dotted red) and the **emissions savings** of the optimized fleet (orange) and the diesel fleet (grey) in relation to the 2019 baseline are shown
- Optionally, the **emissions of individual countries** can be displayed as a bar chart

TCO[1] KPIs

- TCO KPIs are visualized over time: TCO of the **optimized fleet (orange) vs. diesel fleet (grey)**
- Optionally, **individual countries** can also be displayed as bar charts
- The **absolute and relative cost difference** between the optimized and diesel fleet

Fleet development

- The development of the **country-specific fleet** can be viewed for selected years

[1] TCO calculation includes vehicle costs, fuel costs and service costs (tires, motor vehicle tax, insurance, maintenance, interest) only.

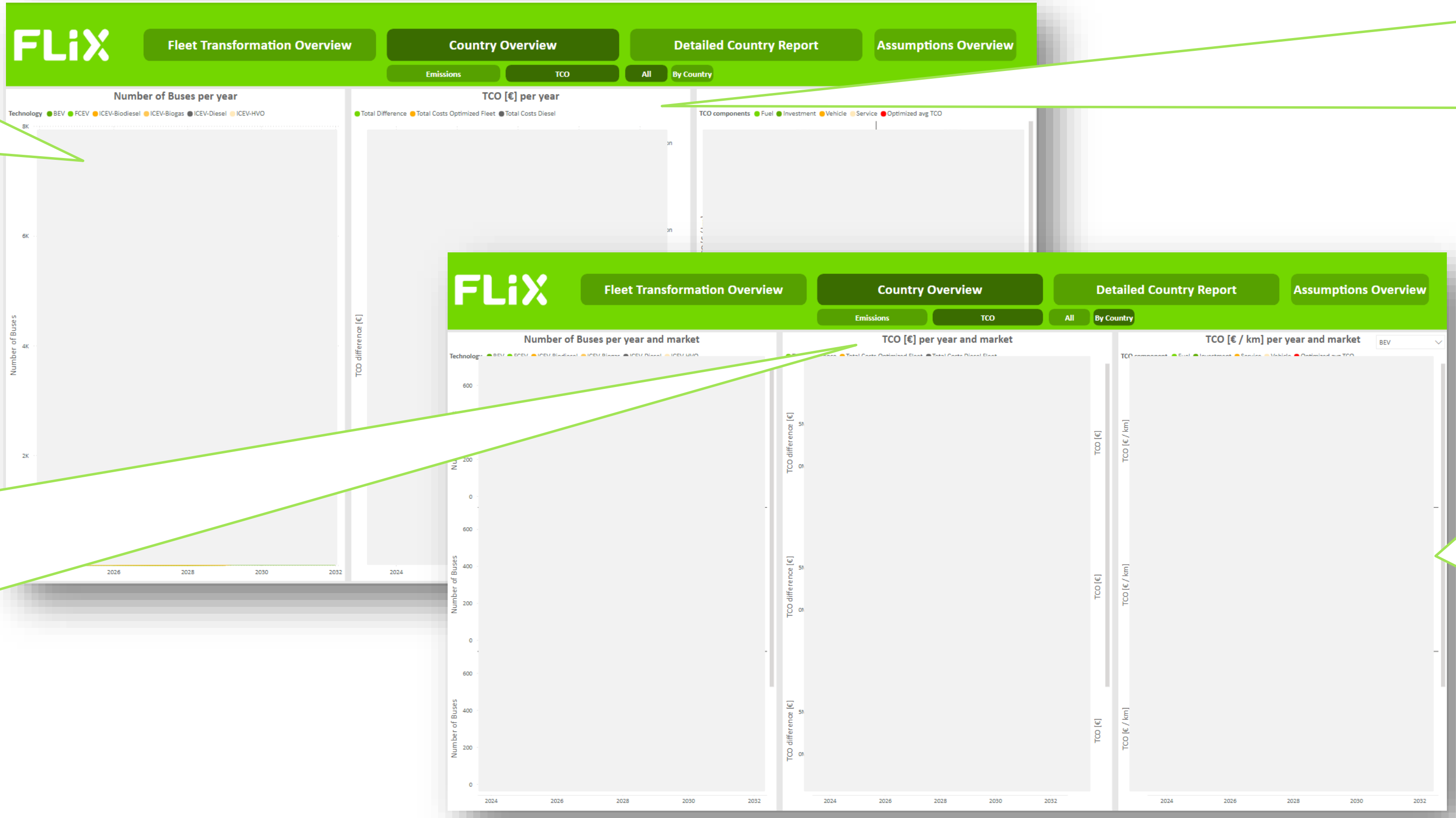
A summary of both emissions and TCO[1] figures at overall fleet or country level is provided by the Country Overview

Fleet Development

- Visualization of the **fleet composition** by technology

Navigation Field

- The user can switch between the **emission or TCO figures**
- Furthermore, the user has the option of viewing the visualizations either at **country or total fleet level**



TCO Over Time

- The TCO of the **optimized and diesel fleet** are shown in comparison
- **The total cost difference** is displayed as a bar chart

Representation of assumptions and results

- The assumed **TCO values split into their components** are shown in the bar chart
- The average cost of the optimized fleet is displayed via the line

[1] TCO calculation includes vehicle costs, fuel costs and service costs (tires, motor vehicle tax, insurance, maintenance, interest) only.

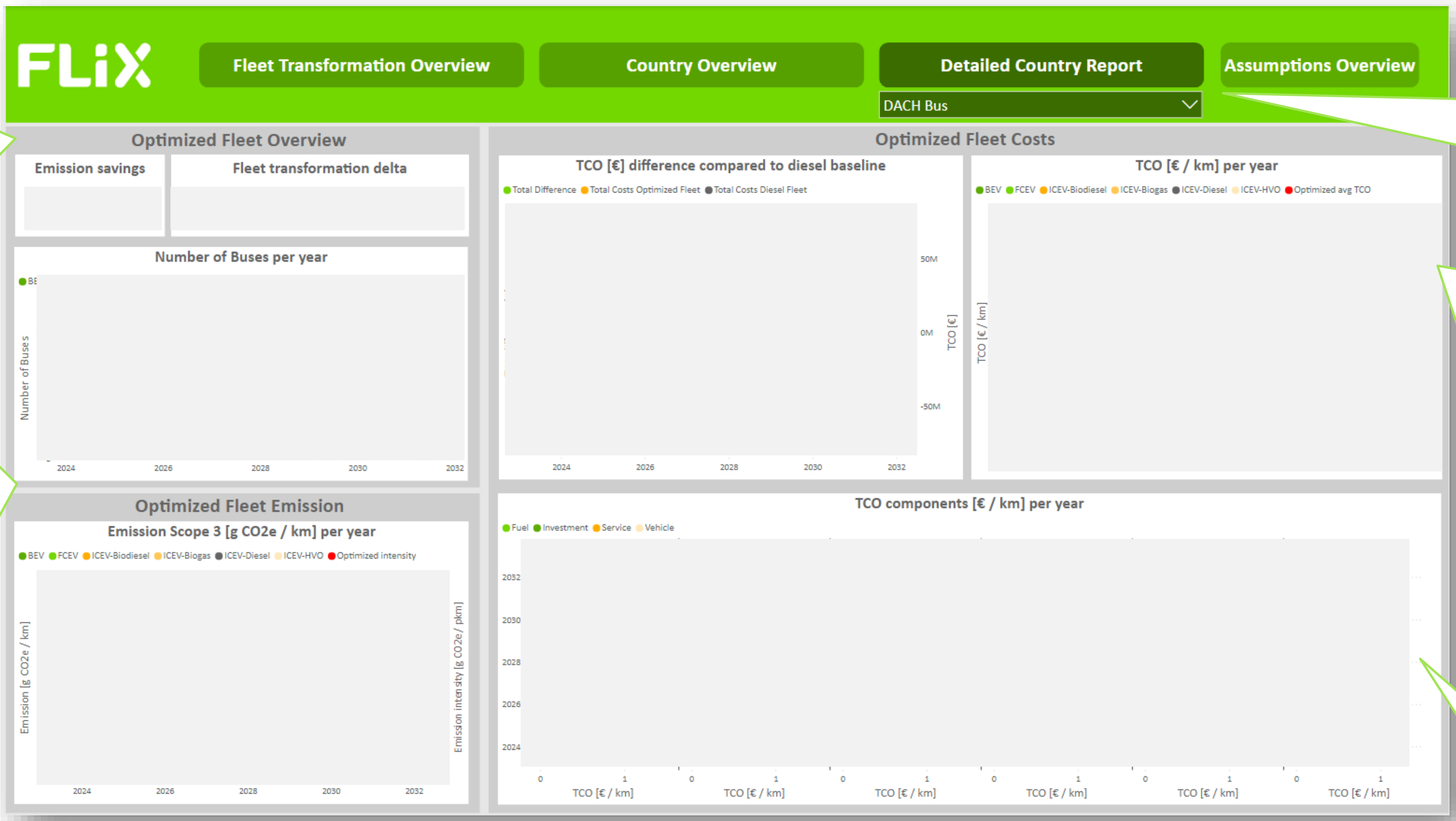
The Detailed Country Report provides more in-depth insights into the underlying assumptions and results for one selected country

KPI Overview

- **Emission and cost savings** of the optimized fleet compared to the diesel fleet

Overview of assumptions and results for emissions

- Bars illustrate the **assumed emissions** per technology
- The red line displays the **emission intensity of the optimized fleet**



Country Filter

- The graphs and metrics shown are displayed for **the selected country**

Optimized fleet costs

- *L:* Cost comparison **optimized (orange) vs diesel fleet (grey)** and absolute difference (bars)
- *R:* **Underlying TCO assumptions** per technology (bar) and **average total fleet TCO** (red line)

TCO[1] components

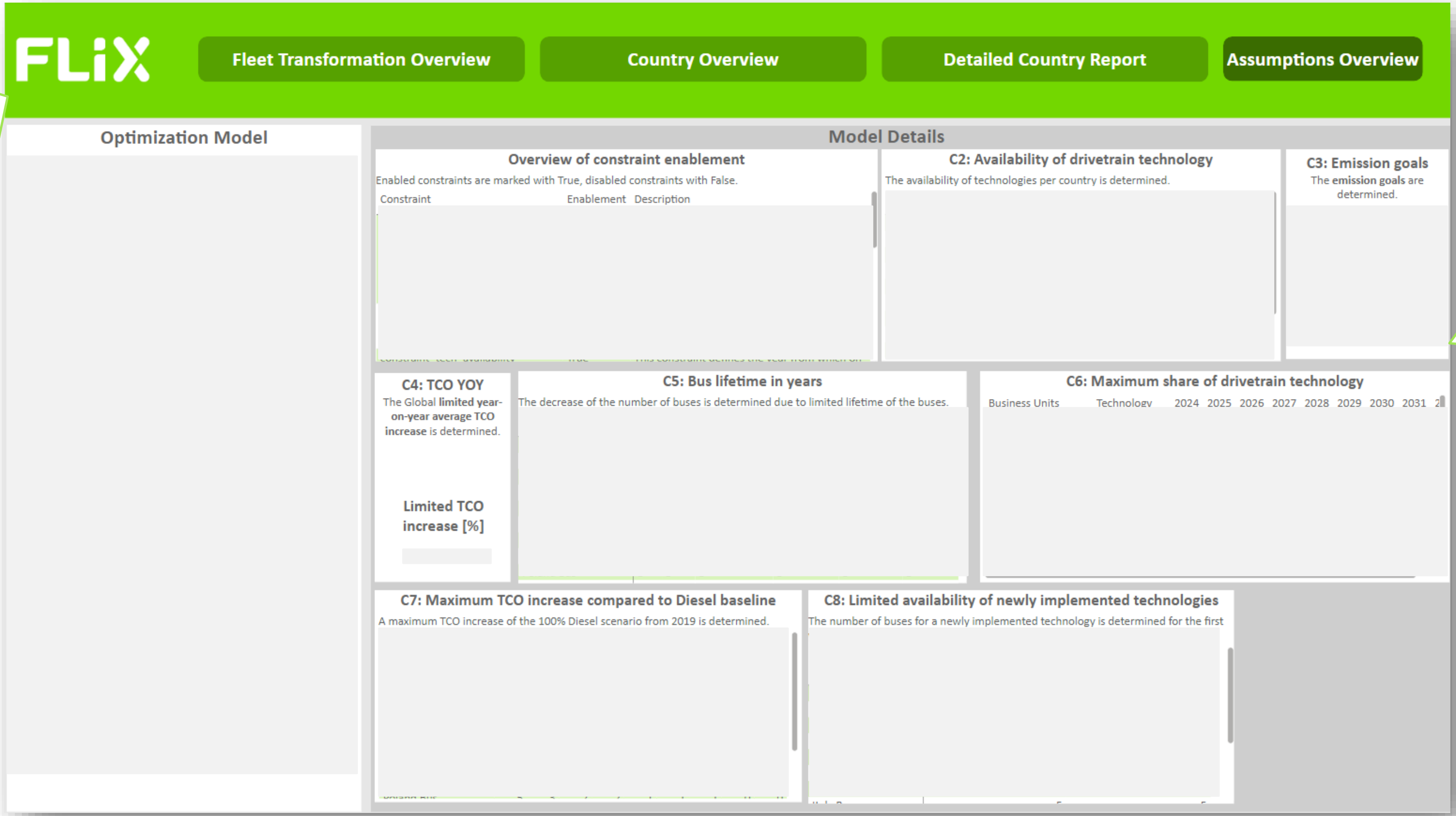
- Breakdown for individual technologies

[1] TCO calculation includes vehicle costs, fuel costs and service costs (tires, motor vehicle tax, insurance, maintenance, interest) only.

A high-level summary of the underlying optimization model and constraints can be found in the Assumptions Overview

Explanations on optimization model and constraints

- Summary of the most important concepts, including the target function used
- Listing of the **constraints in the model**, i.e. which constraints were enabled / disabled during the optimization run
- **Glossary and explanations** for terms and abbreviations used in the tool



Constraint overview

- List of constraints and their parametrization

Next steps in Flix's fleet transformation

Fleet transformation steering

- Apply developed Fleet Optimizer to plan fleet transformation for next years

Emission monitoring

- Further develop emission monitoring framework based on robust data

Pilot projects

- Conduct pilot projects with new ZEV alternative drive technologies to gain experience and prepare for market ramp-up

FLIX

Thank you!

Niclas Bohn

Bibliography

Burnham, A. (2020): *Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool*. Systems Assessment Center, Energy Systems Division, Argonne National Laboratory. https://greet.es.anl.gov/aflee

Cameron Rout, Hu Li, Valerie Dupont, Zia Wadud (2022): *A comparative total cost of ownership analysis of heavy duty on-road and off-road vehicles powered by hydrogen, electricity, and diesel*, Heliyon,Volume 8, Issue 12 , e12417, ISSN 2405-8440, https://doi.org/10.1016/j.heliyon.2022.e12417

Guihua Wang, Marshall Miller, Lewis Fulton (2022): *Estimating Maintenance and Repair Costs for Battery Electric and Fuel Cell Heavy Duty Trucks*

Hooper, A. and Murray, D. (2018): *An Analysis of the Operational Costs of Trucking: 2018 Update (American Transportation Research Institute)*

Hussein Basma and Felipe Rodriguez (2023): *A total cost of ownership comparison of truck decarbonization pathways in Europe*

Mao, S., Basma, H., Ragon, P., Zhou, Y., & Rodríguez, F. (2021): *Total Cost Of Ownership For Heavy Trucks In China: Battery-electric, Fuel Cell Electric, And Diesel Trucks*.

Potkány, Marek & Hlatká, Martina & Debnár, Marek & Hanzl, Jiří. (2018): *Comparison of the Lifecycle Cost Structure of Electric and Diesel Buses*. Naše more. 65. 270-275. DOI: 10.17818/NM/2018/4SI.20

Tanco, M., Cat, L., and Garat, S. (2019*): A break-even analysis for battery electric trucks in Latin America*. J. Clean. Prod. 228, 1354–1367

Thomas Earl, Lucien Mathieu, Stef Cornelis, Samuel Kenny, Carlos Calvo Ambel, James Nix, European Federation for Transport and Environment (T&E) (2018): *Analysis of long haul battery electric trucks in EU: Marketplace and technology, economic, environmental, and policy perspectives*

Zhao, H., Wang, Q., Fulton, L., Jaller, M., & Burke, A. (2018): *A Comparison of Zero-Emission Highway Trucking Technologies*. UC Office of the President: University of California Institute of Transportation Studies. http://dx.doi.org/10.7922/G2FQ9TS7 Retrieved from https://escholarship.org/uc/item/1584b5z9

Zixian Wang, Salvador Acha, Max Bird, Nixon Sunny, Marc E.J. Stettler, Billy Wu, Nilay Shah (2024): *A total cost of ownership analysis of zero emission powertrain solutions for the heavy goods vehicle sector*, Journal of Cleaner Production, Volume 434, 139910, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2023.139910