

Energy efficiency assessment in the context of multimodal passenger transport: From 'well' to 'wheels'

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1st MOVESMART Workshop - 15th October 2015
Bilbao, Spain

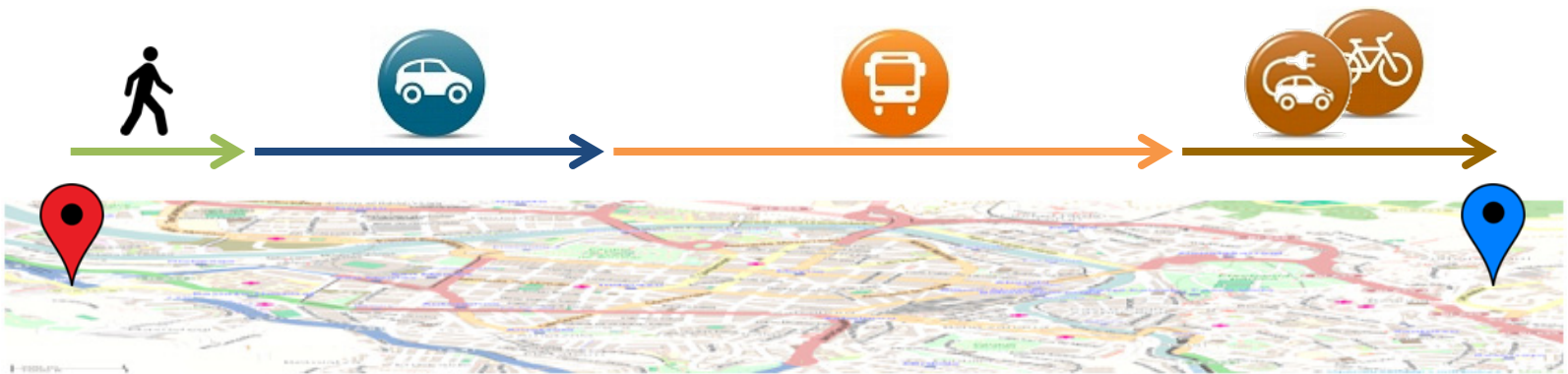
Impact assessment of multimodal routes in relation to the MOVESMART project

Aim

To support the mobility of individuals by assisting the traveler to **combine various means of transportation in an energy-efficient way**

Methodological approach

“Well-to-wheels” analysis of energy consumption/emissions over the operational phase of the life cycle



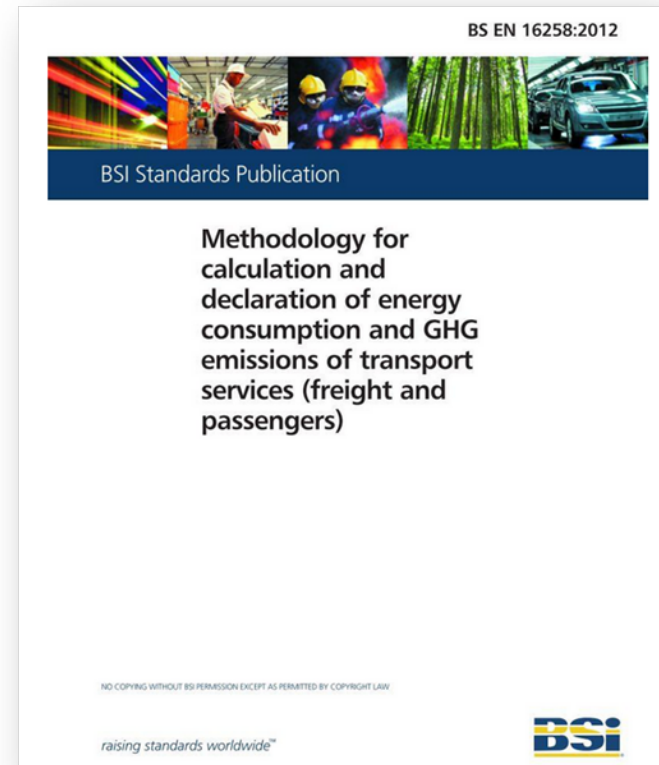
Challenges in relation to MOVESMART objectives

- Scientific:
 - Consideration of **traffic conditions**
 - Inclusion of **electric vehicles** in mobility chains
- Technological:
 - Low **response time**

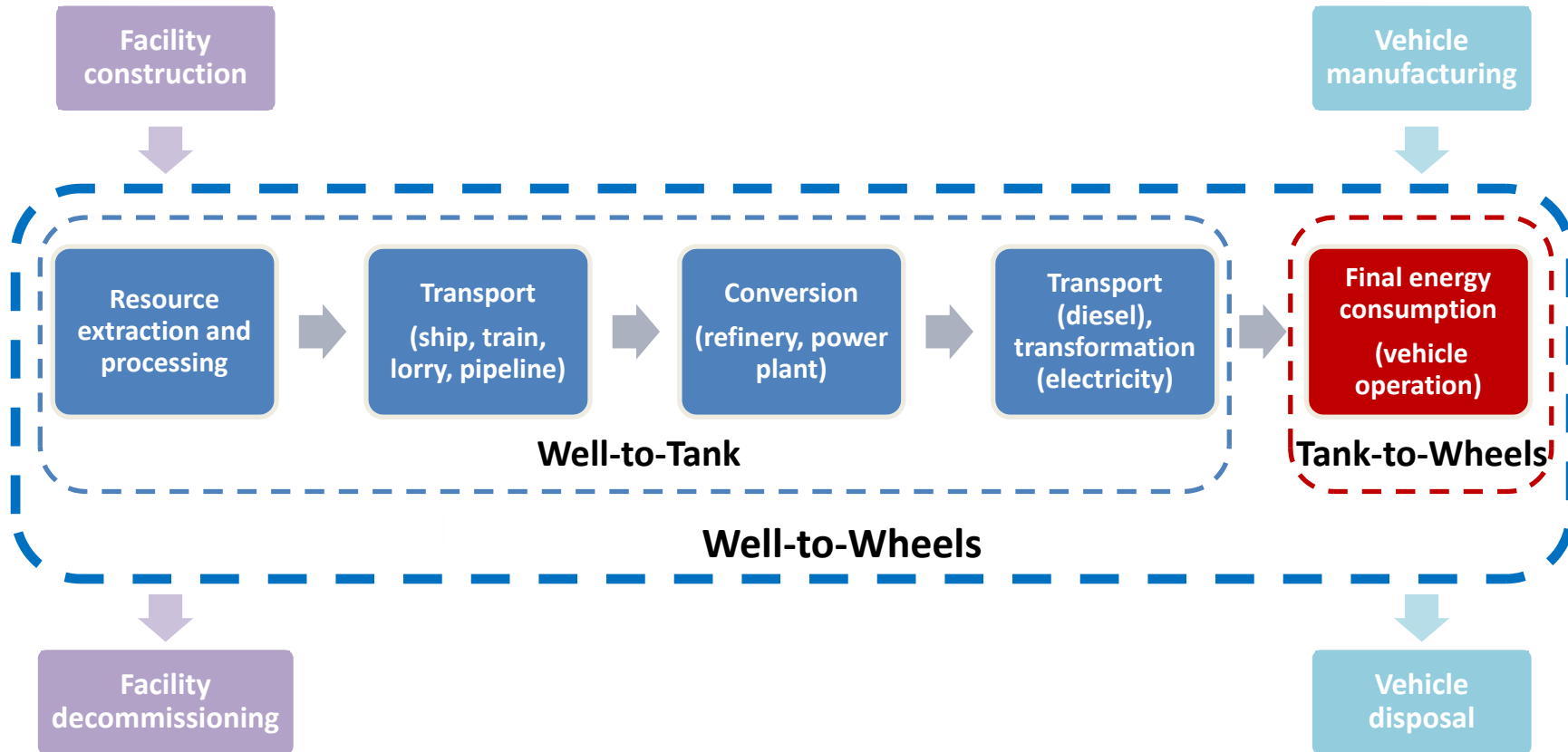


Transport services and standardisation in EU

“The assessment of energy consumption and GHG emissions of a transport service shall include both
vehicle operational processes
and
energy operational processes
that occur during the operational phase of the lifecycle.”

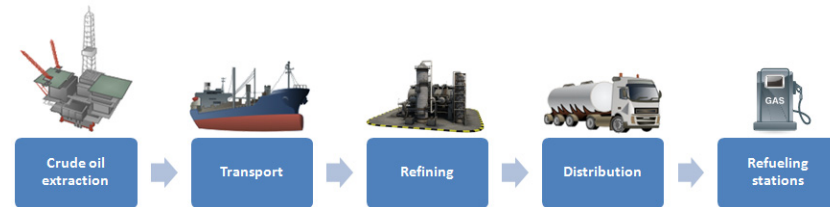


Scope of the analysis

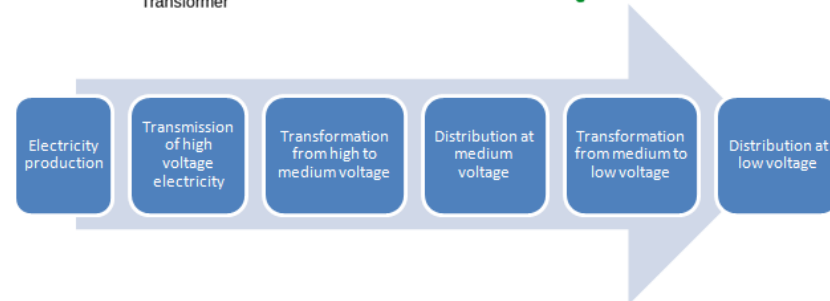
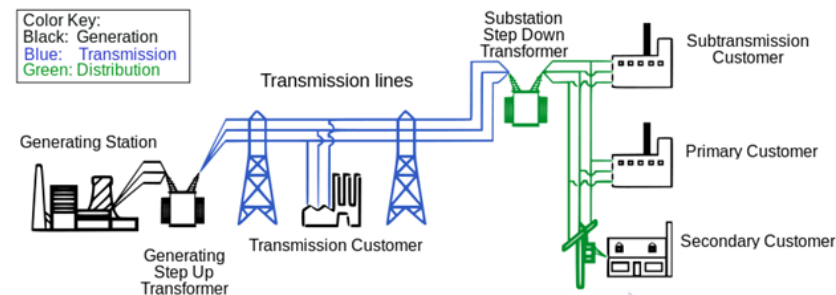


From “well” to “tank”: Energy operational processes (1)

- Modeling of **upstream stages** of the life cycle for:
 - **Transport fuels**
 - **Electricity**
- Tool/Database: SimaPro v8/Ecoinvent v3
- Methods and impact categories:
 - **Global warming potential** (GWP 100a, IPCC 2013)
 - **Cumulative energy demand** (CED v1.08)
- Determination of **upstream energy and emission factors** as part of the life cycle analysis, by:
 - fuel type
 - electricity generation technology (composition of electricity mix)



Example of well-to-tank (WTT) stages of petroleum-based transport fuels

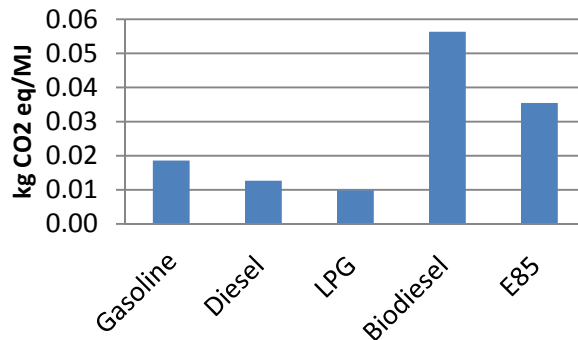


Electricity generation, transmission, transformation and distribution to end users

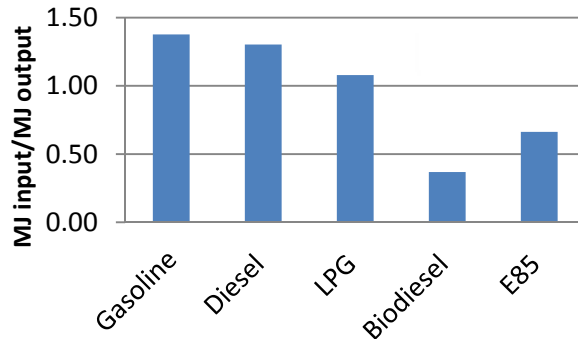
From “well” to “tank”: Energy operational processes (2)

Transport fuels (EU)

Global warming potential (GWP 100a, IPCC 2013)

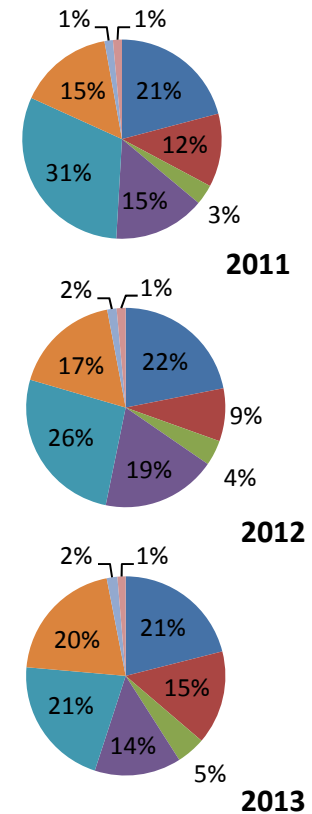
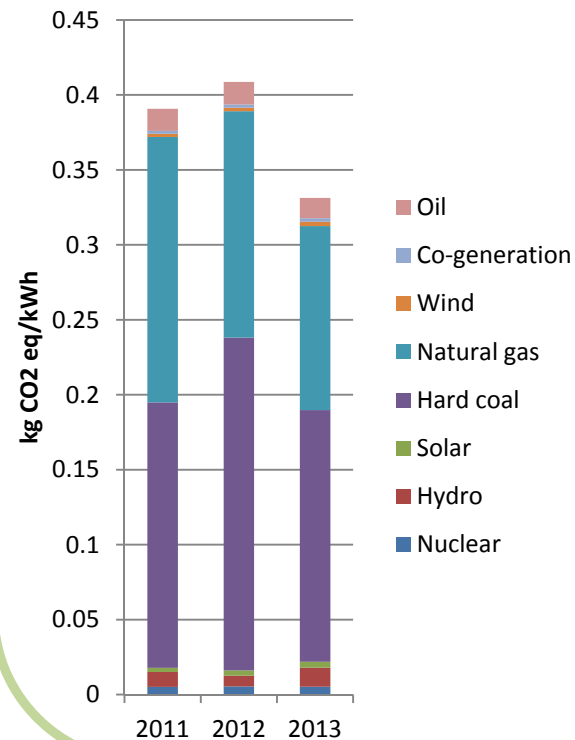


Cumulative energy demand (CED v1.08)



Electricity (ES mix)

Global warming potential (GWP 100a, IPCC 2013)



From “tank” to “wheels”: **Vehicle operational processes** for passenger cars (PCs)

- **Dynamic emission factors** from Handbook Emission Factors for Road Transport (HBEFA)
- Integrated in a MongoDB:
 - Inputs:
 - Traffic situation: <area type, road type, speed limit, level of service>
 - Road gradient: 0%, $\pm 2\%$, $\pm 4\%$, and $\pm 6\%$
 - Car engine technology: Diesel, Petrol (4-stroke), Petrol (2-stroke), LPG, Bifuel CNG/Petrol, Flex-fuel E85
 - Engine size class: Small (<1.4 L), Medium (≥ 1.4 L and <2 L), Large (≥ 2 L)
 - Emission class: Up to Euro 6
 - Fuel type (for bifuel vehicles)
 - Outputs:
 - Emission factors for CO₂, CH₄, N₂O
 - Fuel consumption

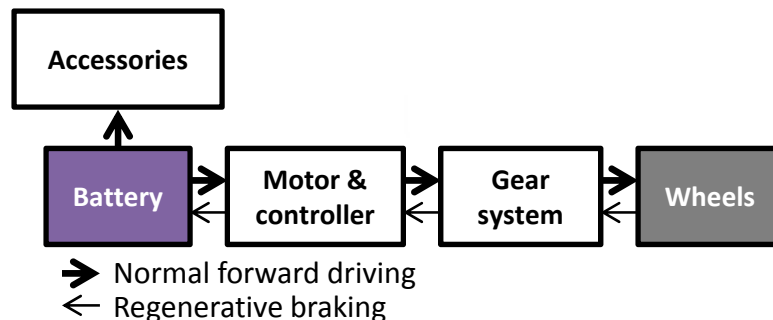


From “tank” to “wheels”: **Vehicle operational processes** for electric vehicles (EVs) (1)

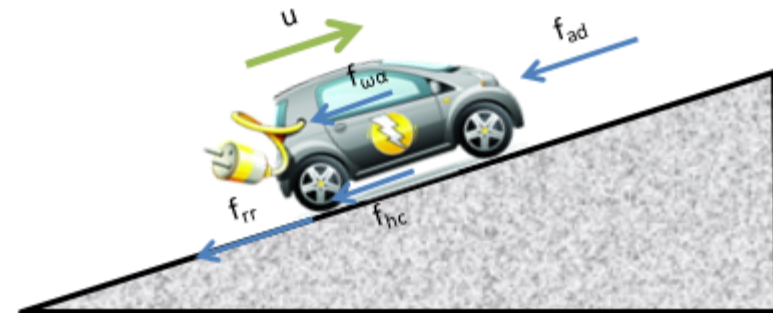
- **Physics-based vehicle model** → Estimation of *traction power*, i.e. power required to overcome the forces opposing to the movement of the vehicle and drive it at speed u

$$P_{te} = F_{te} * u = (F_{ad} + F_{rr} + F_{hc} + F_{la} + F_{\omega\alpha}) * u$$

- **EV components model** → Transformation of *traction power* requirements (at wheels) into *EV battery power* requirements

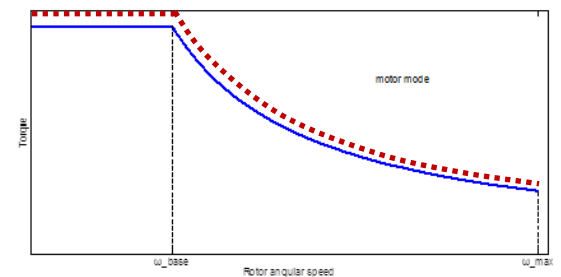
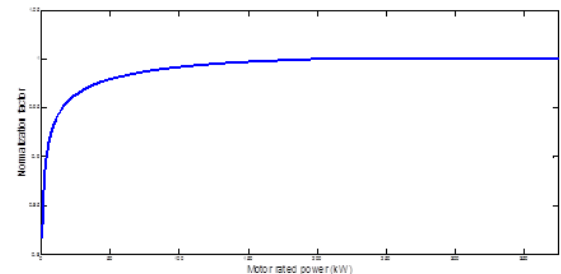
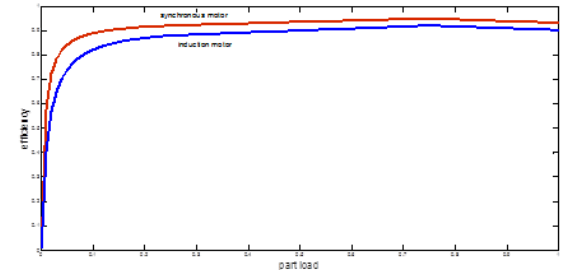


Energy flows in typical battery powered EVs



From “tank” to “wheels”: **Vehicle operational processes** for electric vehicles (EVs) (2)

- **What’s new in modeling of motor operation?**
 - Efficiency-load curves based on motor type:
 - Synchronous
 - Induction
 - Normalisation of efficiency based on motor size
 - Modeling of “overtorque” conditions



From “tank” to “wheels”: **Vehicle operational processes** for electric vehicles (EVs) (3)

- **What’s new in modeling of energy recuperation?**

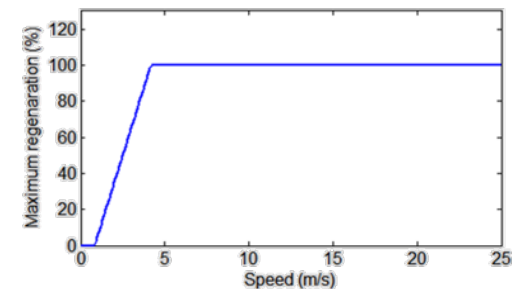
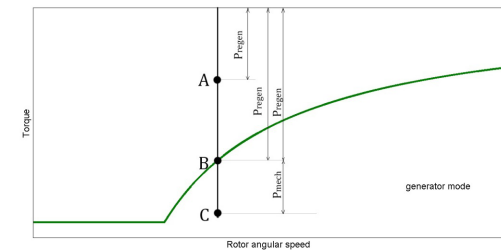
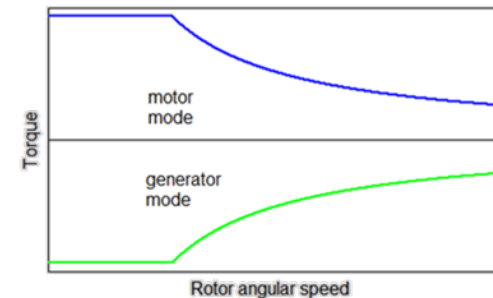
- Symmetric torque-speed curve:

- Motor mode
- Generator mode

- Maximum torque limitation on energy recuperation

- Maximum regeneration capability (%) as function of vehicle speed

- No energy recuperation at low vehicle speeds
- Maximum energy recuperation for vehicle speeds above a minimum threshold



From “tank” to “wheels”: **Vehicle operational processes** for electric cars (1)

- Definition of 3 “average” models based on available electric cars in the market

Low power model

Based on:

- Citroen C-Zero
- Peugeot Ion
- Mitsubishi i-Miev
- VW e-Up!



Medium power model

Based on:

- Renault Zoe
- Renault Fluence ZE
- Nissan Leaf
- KIA Soul



High power model

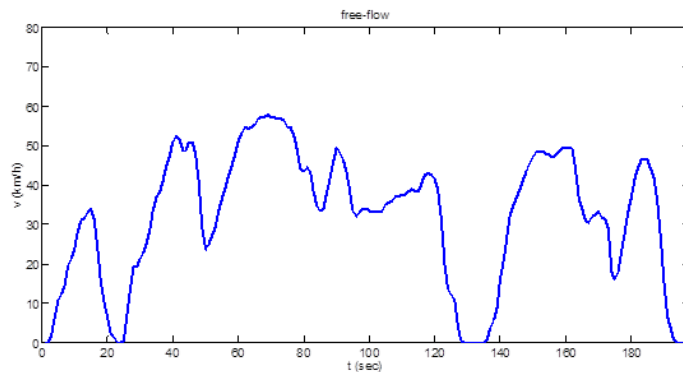
Based on:

- Ford Focus Electric
- BMW i3
- MercedesBenz Class b Electric

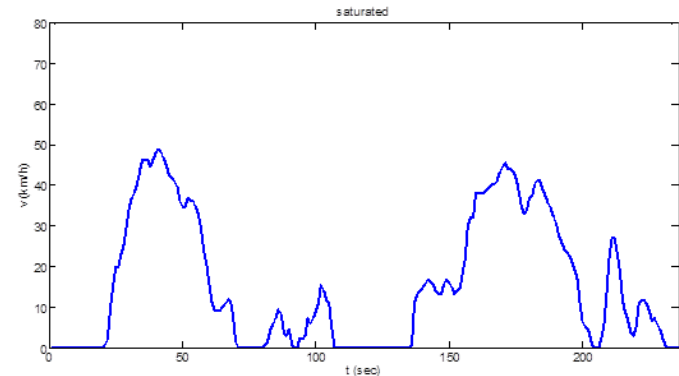


From “tank” to “wheels”: **Vehicle operational processes** for electric cars (2)

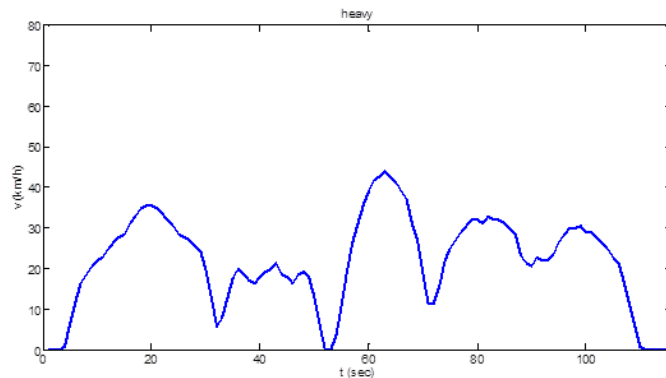
- **Realistic driving cycles for urban traffic conditions**



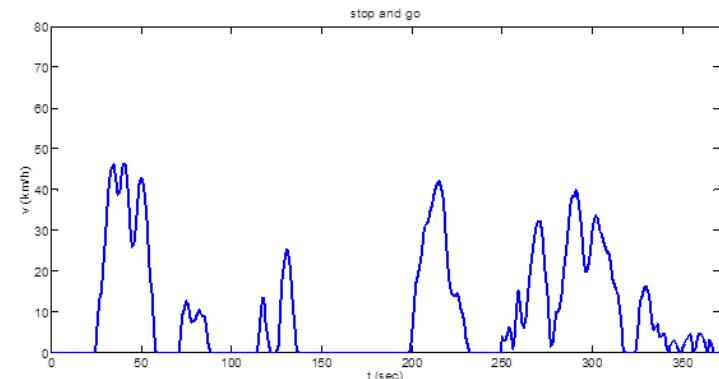
Free flow



Saturated flow



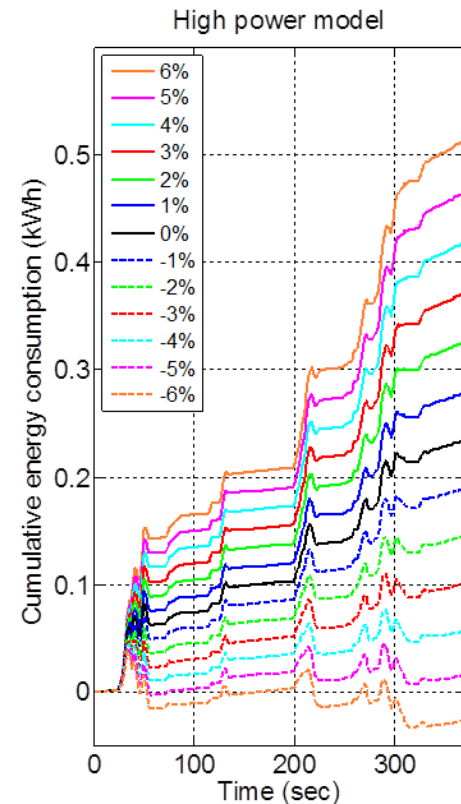
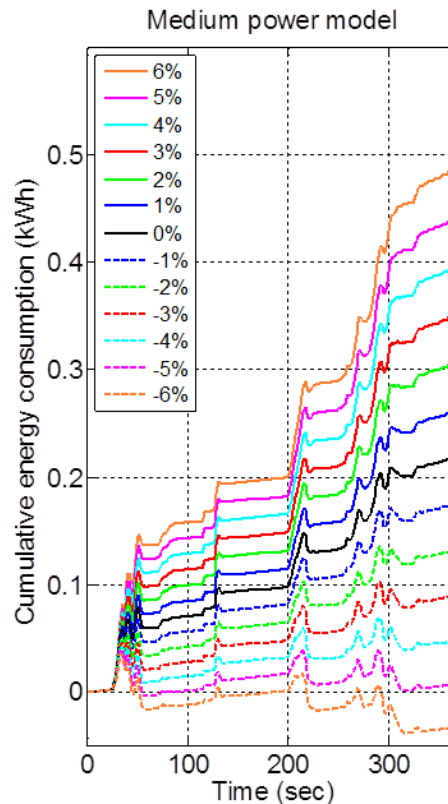
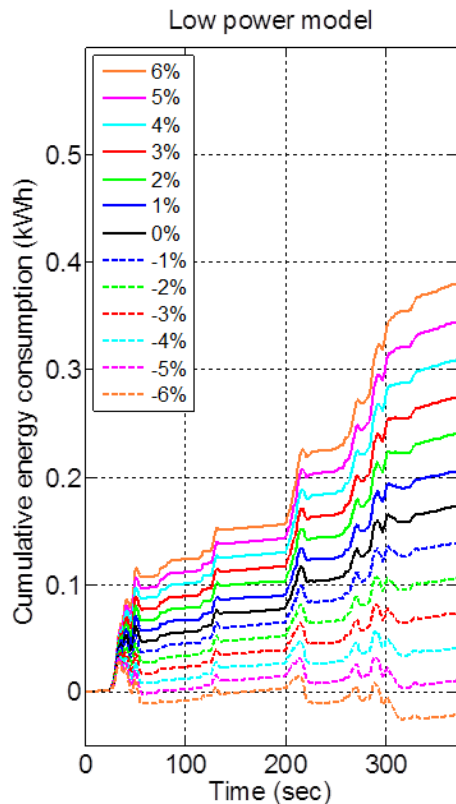
Heavy flow



Stop and go flow

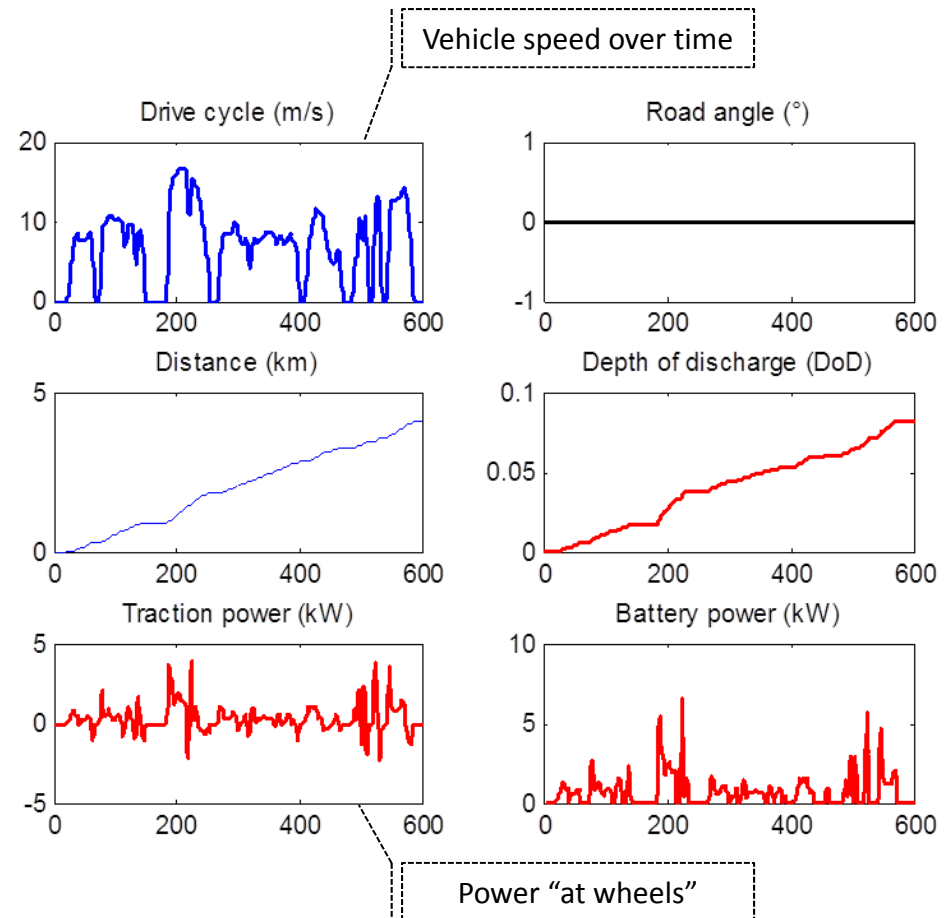
From “tank” to “wheels”: **Vehicle operational processes** for electric cars (3)

- **Extraction of energy consumption factors:** Indicative simulation results for **stop and go flow** and various **road gradients**

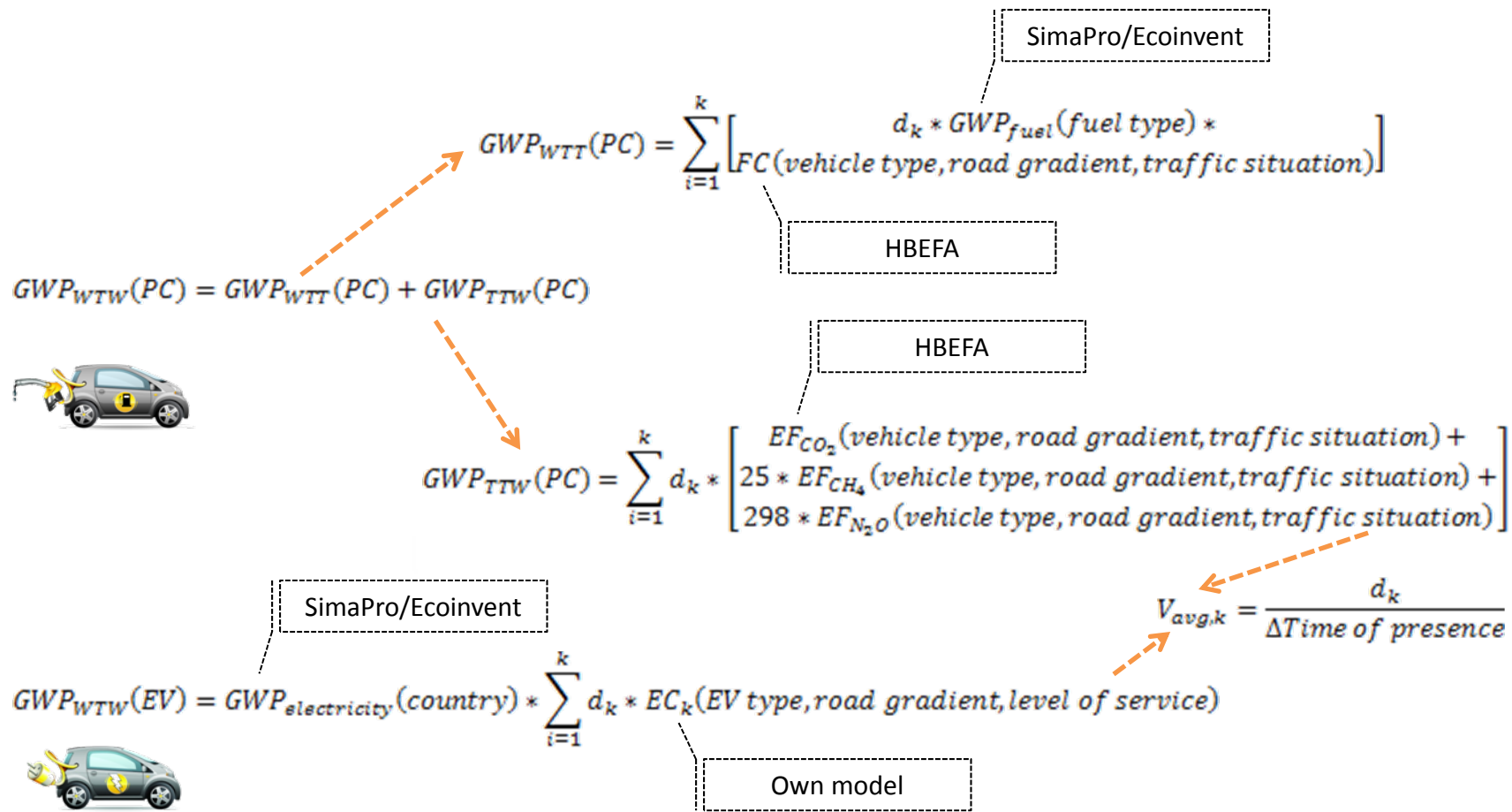


From “tank” to “wheels”: **Vehicle operational processes** for electric scooter

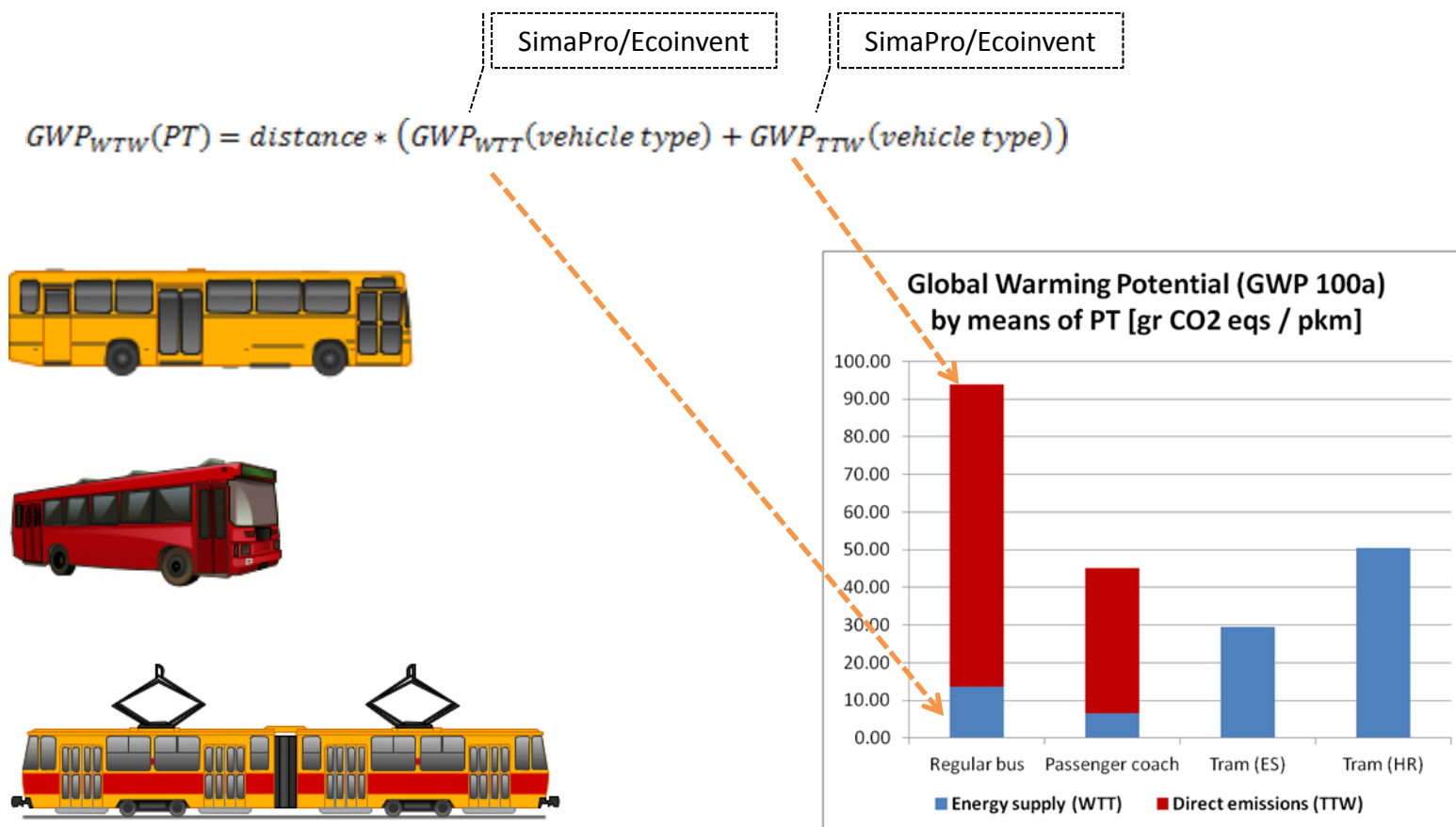
- Model: The Core (GG)
- Regenerative braking: No
- Driving cycle: World Motorcycle Test Cycle (WMTC) – part 1
- Road gradient: 0%



From “well” to “wheels”: Full energy/vehicle pathway for PCs and EVs

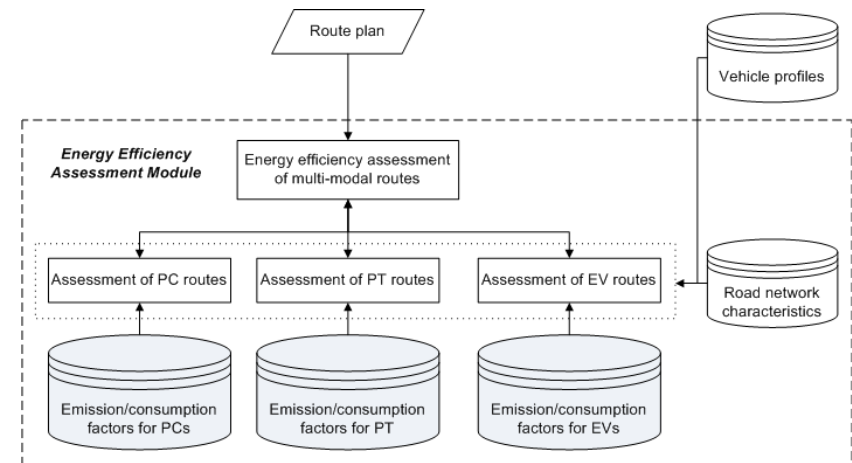


From “well” to “wheels”: Full energy/vehicle pathway for public transport (PT)

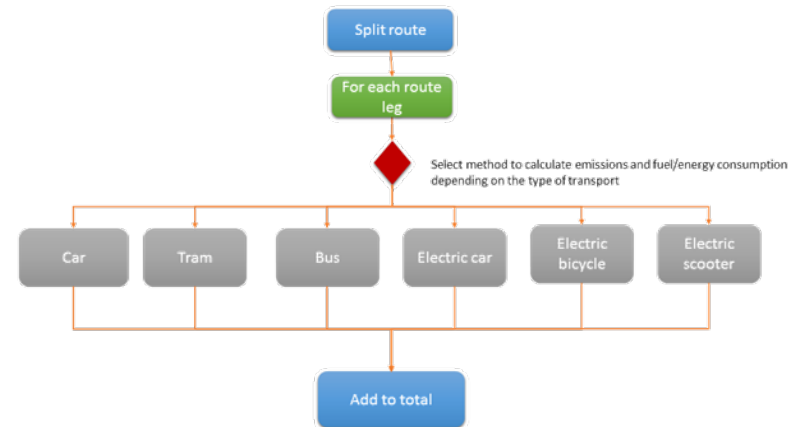


Energy Efficiency Assessment Module as a MOVESMART web-service

- **Purpose:** Integration of components for energy efficiency assessment of multimodal routes

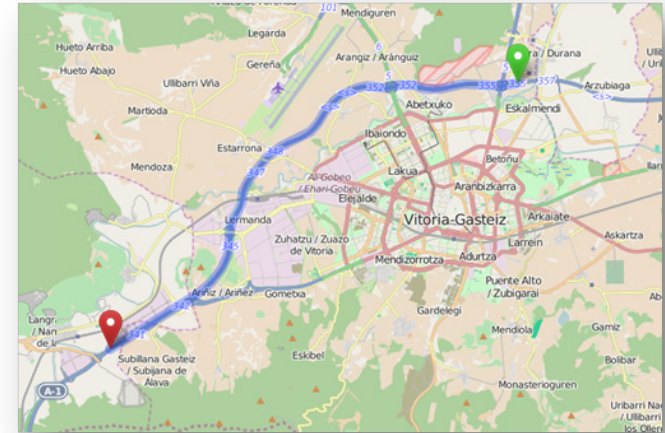


- **Challenge:** Low response time



Concluding remarks

- **Worst case scenario:**
 - 15 km route with PC in Vitoria-Gasteiz
 - 136 road segments
- **Achievement:** Response time <0.6 sec with Intel Core i5 and 4GB RAM
- **Potential improvements:**
 - Current implementation is built with Jersey and runs on Grizzly: Test other frameworks, e.g. Vert.x and Akka
 - Load road network characteristics and energy/consumption databases in memory



Questions?

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