A Taxonomy of Energy Consumption Models for Electric Vehicles

Daniel Alejandro Villa
Alejandro Montoya

Motivation of the study

Motivation of the study

- There is a necessity to reduce greenhouse gas (GHG) emissions for reaching the proposed goal by 2050.

Percentages by sector to achieve and overall 80% GHG reduction below 1990 levels in Europe Postulated by McKinsey Company	
Power	**95% to 100%**
Road Transport	95%
Air Sea Transport	50%
Industry	40%
Buildings	95%
Waste	100%
Agriculture	20%

Taken from [26]

Motivation of the study

- Light Duty Vehicles (LDV) have to reduce their emissions in 83.1% compared to 2009 in the United States.
- EVs have limited autonomies.

Examples of EV autonomies	
Car model	**Autonomy (km)**
Nissan Leaf	378
Peugeot ion 5	150

Examples of ICV autonomies	
Car model	**Autonomy (km)**
Chevrolet Spark LT	486
Toyota Corolla 2017	666

Taken from [27-30]

- Long charging times for EVs (6-11 hours for the Peugeot ion 5).
- Quick charge takes 15 min for 50% and 30 min for 80% (Peugeot ion 5).

Motivation of the study

- Consumption models are necessary to reduce range anxiety.

Charging stations in Universidad EAFIT

Motivation of the study

- Professionals in transportation planning use consumption estimations in their routing models as **electric vehicle routing problem, shortest path problem with charging decisions, charging station location problem**.
- Some parameters are hard to determine.
- It is necessary to identify what model to use.

Focus of the study

We propose a classification of the models, depending on their characteristics.

Classification of the models

Classification of the models

- Publications with high amount of citations.
- Researches recently published.
- 18 papers reviewed, 25 models found.
- Three classifications for the models based on: the input parameters, the type of approach, and the source of the input values.
- Error measures in the models are represented in different ways.

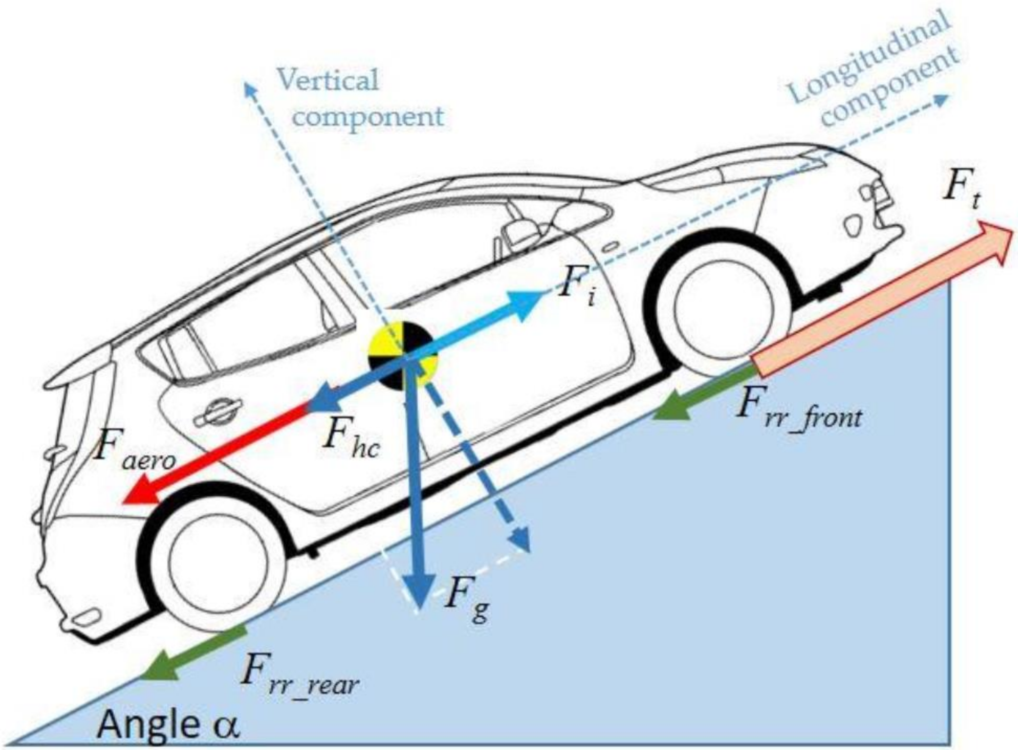
Classification of the models

Classification by parameters

Classification of the models

Classification by parameters

- We identify different types of parameters related to the route, to the vehicle and to the weather conditions

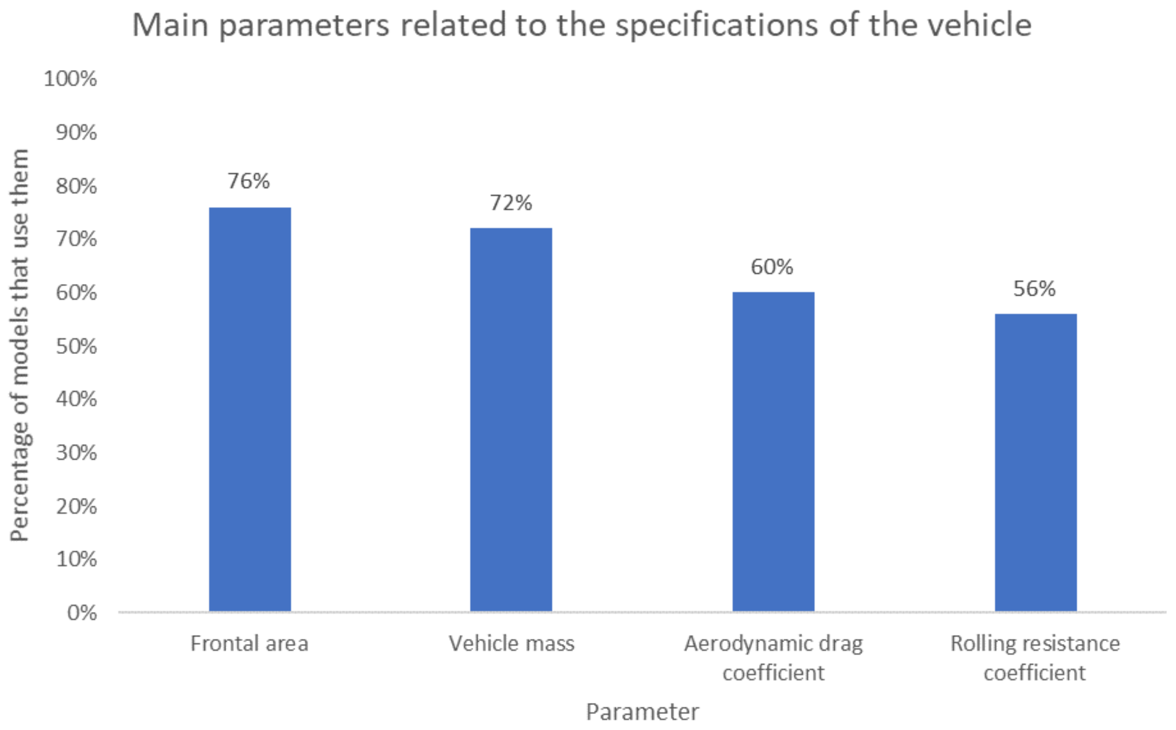


Taken from [23]

Classification of the models

Classification by parameters

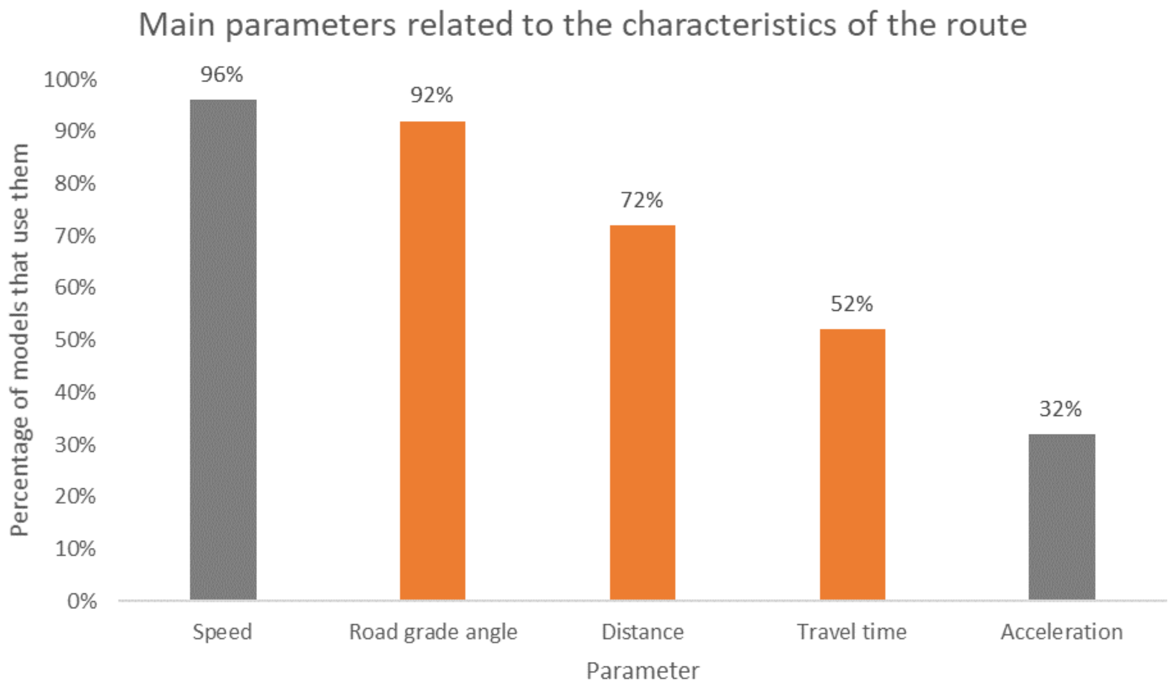
- We found some parameters related to the technical specifications of the vehicle



Classification of the models

Classification by parameters

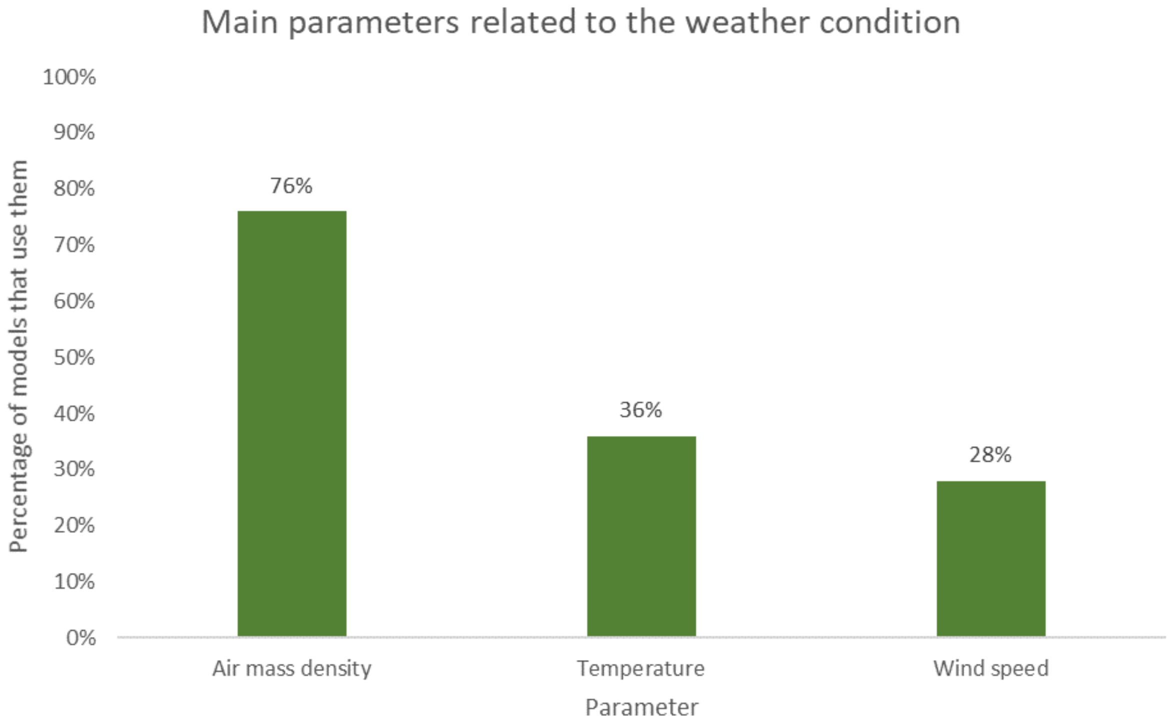
- We found some parameters related to the characteristics of the route and parameters that depend on both technical specifications and characteristics of the route.



Classification of the models

Classification by parameters

- We found parameters related to the weather conditions



- Auxiliaries affect the autonomy and are related to weather conditions.

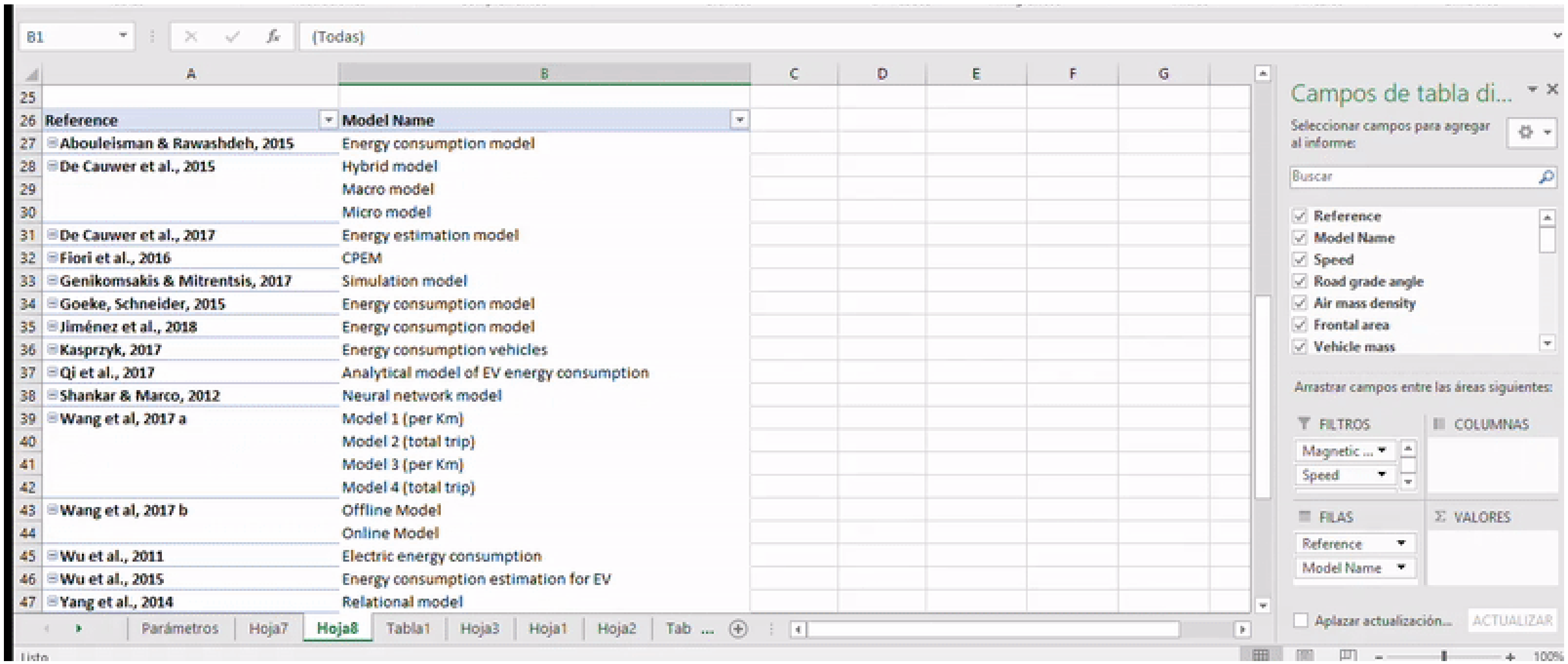
Classification of the models

Classification by parameters

- For professionals in transportation planning, the ease of use of the models will depend on the ease of finding the parameters.
- Professionals in transportation planning are not always experts in mechanics.
- We looked for the parameters related to the technical specifications of the Nissan Leaf presented by Sherman (2012).
- We found that with those parameters, it is feasible to implement the next models: the energy consumptions models presented by Abousleiman & Rawashdeh (2015) and Kasprzyk (2017), the Comprehensive Power-based EV Energy consumption Model (CPEM) presented by Fiori et al., (2016) and the relational model presented in Yang et al., (2014).

Classification of the models

Classification by parameters



Reference	Model Name
Abouleisman & Rawashdeh, 2015	Energy consumption model
De Cauwer et al., 2015	Hybrid model
	Macro model
	Micro model
De Cauwer et al., 2017	Energy estimation model
Fiori et al., 2016	CPEM
Genikomsakis & Mitrentsis, 2017	Simulation model
Goeke, Schneider, 2015	Energy consumption model
Jiménez et al., 2018	Energy consumption model
Kasprzyk, 2017	Energy consumption vehicles
Qi et al., 2017	Analytical model of EV energy consumption
Shankar & Marco, 2012	Neural network model
Wang et al, 2017 a	Model 1 (per Km)
	Model 2 (total trip)
	Model 3 (per Km)
	Model 4 (total trip)
Wang et al, 2017 b	Offline Model
	Online Model
Wu et al., 2011	Electric energy consumption
Wu et al., 2015	Energy consumption estimation for EV
Yang et al., 2014	Relational model

Classification of the models

Classification by type of approach

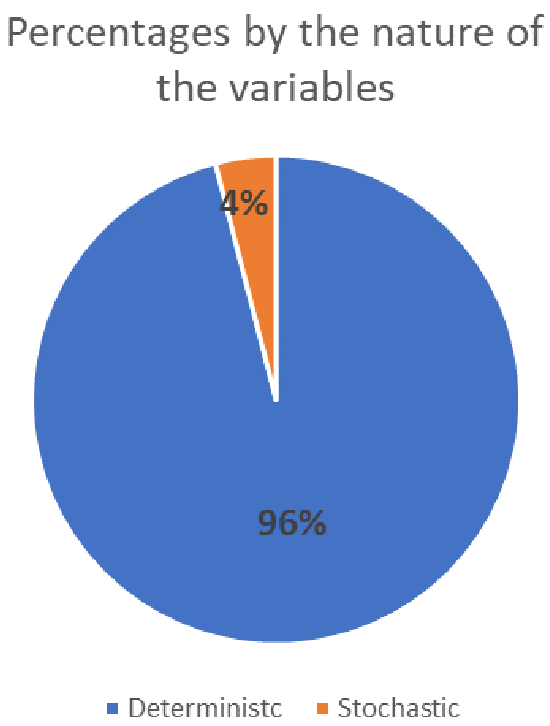
Classification of the models

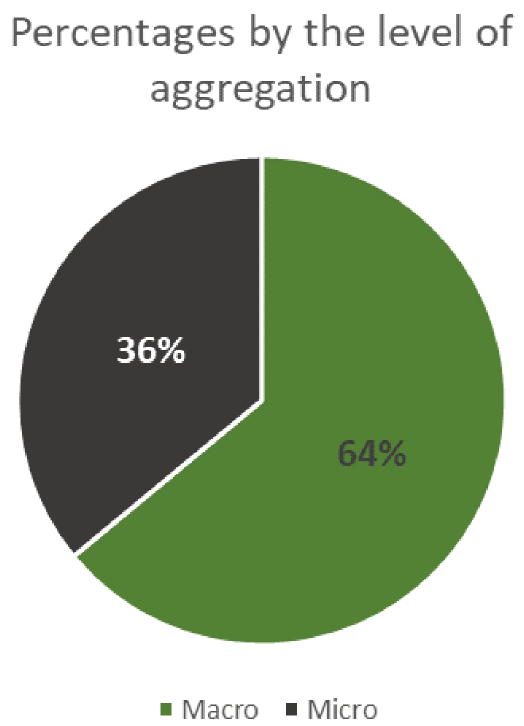
Classification by type of approach

- First, classification of the models as deterministic or stochastic (whether there is randomness or not).
- Second, classification of the models as micro or macro, depending on the level of aggregation and the use of GPS.

Classification of the models

Classification by type of approach





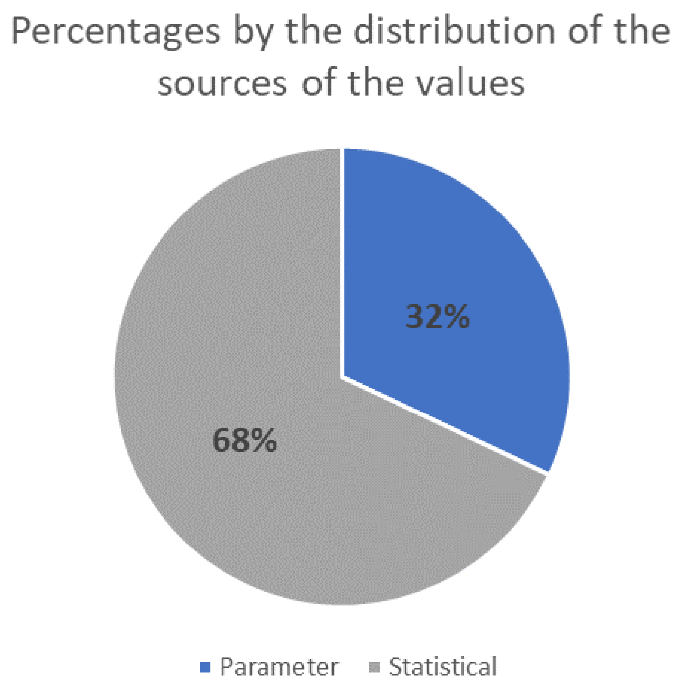
Classification of the models

Classification by the source of the input parameter values

Classification of the models

Classification by the source of the input parameter values

- Two types of sources: physical characteristics or statistical means (e.g. linear regressions).



Conclusions and perspectives

Conclusions

- We identified three classifications of energy consumption models for EVs, based on 18 papers and 25 models.
- We found 23 different parameters that are being used in different energy consumption models. 11 of these parameters are used in more than half of the reviewed models.
- 96% of the reviewed models use a deterministic approach.
- 36% of the reviewed models use micro aggregation, while the remaining 64% use macro aggregation.
- 68% of the reviewed models use statistical means for the input parameters, which implies that those parameters are specific oriented to the conditions of the regression made.

Conclusions

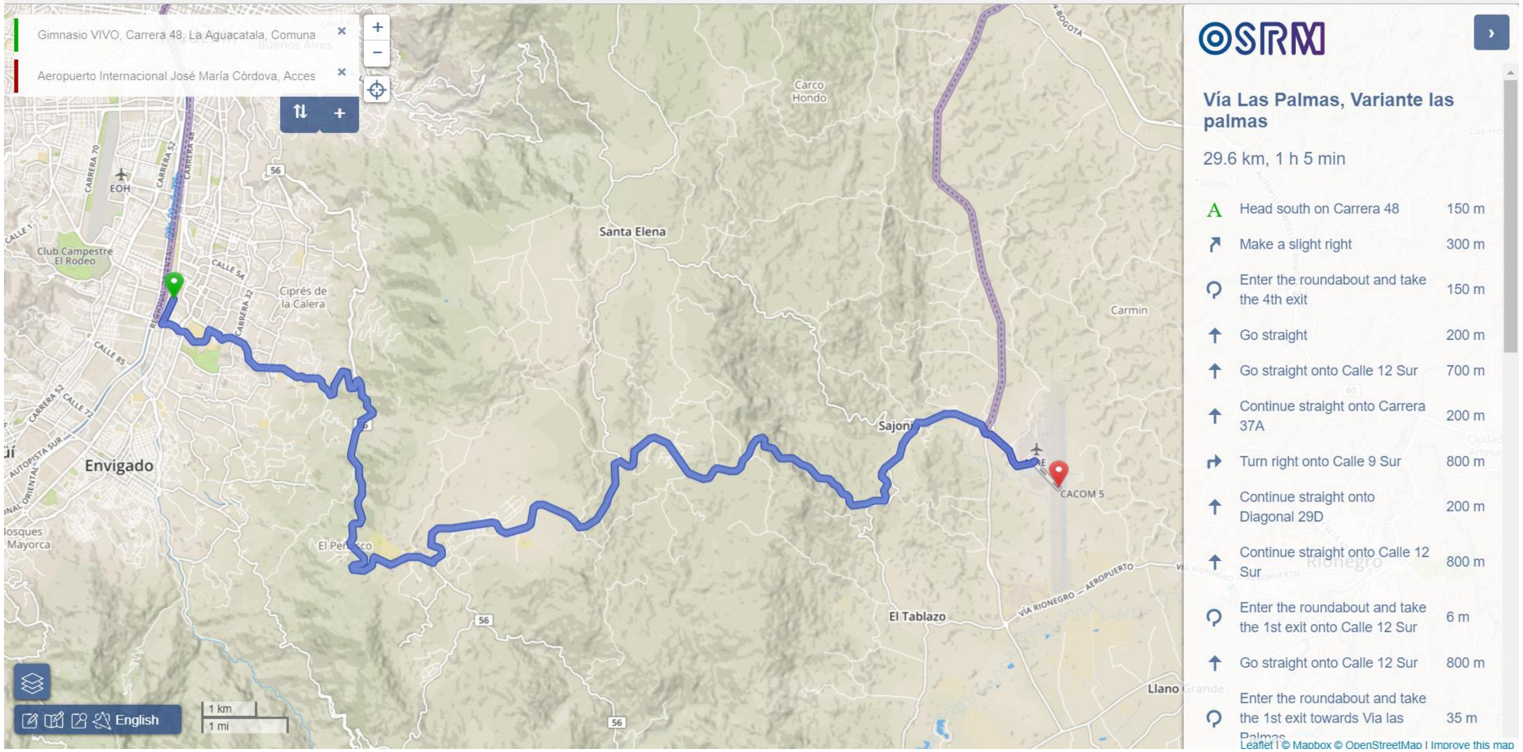
- We found that for the Nissan Leaf it is feasible to implement the next models: the energy consumptions models presented by Abousleiman & Rawashdeh (2015) and Kasprzyk (2017), the Comprehensive Power-based EV Energy consumption Model (CPEM) presented by Fiori et al., (2016) and the relational model presented in Yang et al., (2014).

Perspectives

- Comparing different models, under the same conditions of route, with the real consumption of the vehicles, for determining the one that better fits.
- We are going to measure the consumptions of different EVs. We will test the vehicles: Nissan Leaf V1, Kia Soul, BYD e6, BMW i3, Renault Twizy and Renault Zoé, under the same conditions of route.
- We will implement a tool for estimating consumption with the different models that we are going to test.

Perspectives

- Visualization of the tool



Visualization of OSRM interface, for the implementation of consumption models

References

[1] S. Pelletier, O. Jabali, G. Laporte, and M. Veneroni, “Battery degradation and behaviour for electric vehicles: Review and numerical analyses of several models,” Transportation Research Part B: Methodological, vol. 103, pp. 158–187, 2017.

[2] J. Larminie and J. Lowry, Electric Vehicle Technology Explained. John Wiley & Sons Ltd., 2004.

[3] J. Wang, K. Liu, and T. Yamamoto, “Improving electricity consumption estimation for electric vehicles based on sparse GPS observations,” Energies, vol. 10, no. 1, pp. 19–22, 2017.

[4] A. Montoya, C. Gueret, J. E. Mendoza, and J. G. Villegas, “The electric vehicle routing problem with nonlinear charging function,” Transportation Research Part B: Methodological, 2017.

[5] A. Artmeier, J. Haselmayr, M. Leucker, and M. Sachenbacher, “The shortest path problem revisited: Optimal routing for electric vehicles,” Springer, 2010.

[6] J. Dong, C. Liu, and Z. Lin, “Charging infrastructure planning for promoting battery electric vehicles: An activity-based approach using multiday travel data,” Transportation Research Part C: Emerging Technologies, 2014.

[7] C. De Cauwer, J. Van Mierlo, and T. Coosemans, “Energy consumption prediction for electric vehicles based on real-world data,” Energies, vol. 8, no. 8, pp. 8573–8593, 2015.

[8] X. Qi, G. Wu, K. Boriboonsomsin, and M. J. Barth, “Data-driven decomposition analysis and estimation of link-level electric vehicle energy consumption under real-world traffic conditions,” Transportation Research Part D: Transport and Environment, no. April, pp. 0–1, 2017. [Online]. Available: http://dx.doi.org/10.1016/j.trd.2017.08.008

References

[9] X. Wu, D. Freese, A. Cabrera, and W. A. Kitch, “Electric vehicles’ energy consumption measurement and estimation,” Transportation Research Part D: Transport and Environment, vol. 34, pp. 52–67, 2015. [Online]. Available: http://dx.doi.org/10.1016/j.trd.2014.10.007

[10] Z. Yi and P. H. Bauer, “Adaptive multiresolution energy consumption prediction for electric vehicles,” IEEE Transactions on Vehicular Technology, vol. 66, no. 11, pp. 10 515–10 525, 2017.

[11] D. Wu, D. C. Aliprantis, and K. Gkritza, “Electric Energy and Power Consumption by Light-Duty Plug-In Electric Vehicles,” IEEE Transactions on Power Systems, vol. 26, no. 2, pp. 738–746, 2011.

[12] R. Shankar and J. Marco, “Method for estimating the energy consumption of electric vehicles and plug-in hybrid electric vehicles under realworld driving conditions,” IET intelligent transport systems, vol. 7, no. 1, pp. 138–150, 2012.

[13] S. C. Yang, M. Li, Y. Lin, and T. Q. Tang, “Electric vehicle’s electricity consumption on a road with different slope,” Physica A: Statistical Mechanics and its Applications, vol. 402, pp. 41–48, 2014.

[14] D. Goeke and M. Schneider, “Routing a mixed fleet of electric and conventional vehicles,” European Journal of Operational Research, vol. 245, no. 1, pp. 81–99, 2015. [Online]. Available: http://dx.doi.org/10.1016/j.ejor.2015.01.049

[15] R. Zhang and E. Yao, “Electric vehicles’ energy consumption estimation with real driving condition data,” Transportation Research Part D: Transport and Environment, vol. 41, pp. 177–187, 2015. [Online]. Available: http://dx.doi.org/10.1016/j.trd.2015.10.010

[16] R. Abousleiman and O. Rawashdeh, “Energy consumption model of an electric vehicle,” IEEE, no. 1, 2015.

References

[17] C. Fiori, K. Ahn, and H. A. Rakha, "Power-based electric vehicle energy consumption model: Model development and validation," Applied Energy, vol. 168, pp. 257–268, 2016. [Online]. Available: http://dx.doi.org/10.1016/j.apenergy.2016.01.097

[18] X. Yuan, C. Zhang, G. Hong, X. Huang, and L. Li, "Method for evaluating the real-world driving energy consumptions of electric vehicles," Sustainable Cities and Society, vol. 141, pp. 1955–1968, 2017.

[19] L. Kasprzyk, "Modelling and analysis of dynamic states of the leadacid batteries in electric vehicles," Maintenance and Reliability, vol. 19, no. 2, pp. 229–236, 2017.

[20] K. N. Genikomsakis and G. Mitrentsis, "A computationally efficient simulation model for estimating energy consumption of electric vehicles in the context of route planning applications," Transportation Research Part D: Transport and Environment, vol. 50, pp. 98–118, 2017. [Online]. Available: http://dx.doi.org/10.1016/j.trd.2016.10.014

[21] C. De Cauwer, W. Verbeke, T. Coosemans, S. Faid, and J. Van Mierlo, "A data-driven method for energy consumption prediction and energyefficient routing of electric vehicles in real-world conditions," Energies, vol. 10, no. 5, 2017.

[22] J. Wang, I. Besselink, and H. Nijmeijer, "Battery electric vehicle energy consumption prediction for a trip based on route information," SAGE journals, pp. 0–48, 2013.

[23] D. Jimnez, S. Hernndez, J. Fraile-Ardanuy, J. Serrano, R. Fernndez, and F. lvarez, "Modelling the effect of driving events on electrical vehicle energy consumption using inertial sensors in smartphones," Energies,vol. 11, no. 2, p. 412, 2018.

References

[24] D. Sherman, “2012 nissan leaf sl,” https://www.caranddriver.com/features/drag-queens-aerodynamicscompared-comparison-test-fifth-place-nissan-leaf-page-2, 2014.

[25] J. Restrepo, J. Rosero, and S. Tellez, “Performance testing of electric vehicles on operating conditions in Bogota DC, Colombia,” ´ 2014 IEEE PES Transmission and Distribution Conference and Exposition, PES T and D-LA 2014 - Conference Proceedings, vol. 2014-Octob, 2014.

[26] C. E. Sandy Thomas, “How green are electric vehicles?,” Int. J. Hydrogen Energy, vol. 37, no. 7, pp. 6053–6062, 2012.

[27] Nissan, “Nuevo Nissan Leaf, Autonomía y recarga.” [Online]. Available: https://www.nissan.es/vehiculos/nuevos-vehiculos/leaf/autonomia.html.

[28] The Car Guide, “Toyota Corolla 2017,” 2017. [Online]. Available: https://www.guideautoweb.com/en/makes/toyota/corolla/2017/specifications/ce/.

[29] Peugeot, “Información técnica Peugeot ion coche eléctrico.” [Online]. Available: http://www.peugeot.es/gama/selector-de-coches/peugeot-ion/informacion-tecnica.html.

[30] The Car Guide, “Chevrolet Spark 2017,” 2017. [Online]. Available: https://www.guideautoweb.com/en/makes/chevrolet/spark/2017/specifications/ls/

Thanks for your attention!