Renewable and Sustainable Energy Reviews • Volume 148 • September 2021 • Article number 111215

Document type
Article

Source type
Journal

ISSN
13640321

DOI
10.1016/j.rser.2021.111215

Route prioritization of urban public transportation from conventional to electric buses: A new methodology and a study of case in an intermediate city of Ecuador

Wenz K.-P.[a], Serrano-Guerrero X.[b], Barragán-Escandón A.[b], González L.G.[c], Clairand J.-M.[d]

[a] ReLUT (Research Lab for Urban Transport), Frankfurt University of Applied Sciences, Frankfurt am Main, 60318, Germany

[b] Grupo de Investigación en Energías, Universidad Politécnica Salesiana, Cuenca, 010103, Ecuador

[c] Departamento de Eléctrica, Electrónica y Telecomunicaciones (DEET) – Universidad de Cuenca, Av. 12 de abril, Cuenca, 010103, Ecuador

[d] Facultad de Ingeniería y Ciencias Aplicadas, Universidad de las Américas, José Queri, Quito, 170125, Ecuador

Abstract

Electric vehicles have attracted increasing interest in recent years owing to their reduced environmental impact. This is particularly so in the case of vehicles for public transportation, such as buses. However, the transition from internal combustion engine buses to electric buses (EBs) is accompanied by new challenges for the power grid, particularly in developed countries. This paper proposes a new methodology to address the transition of urban public transportation from conventional buses to EBs by route prioritization. The scores of each criterion are weighted using a multi-criteria technique. The case study of Cuenca, Ecuador, which is an intermediate Andean city, is considered. The results indicate that the proposed methodology enables the establishment of route prioritization for the transition toward electric mobility. The replacement to EBs of the three best-performing bus lines (50 buses) avoids using 1328 gallons of diesel each day and, thereby, over 13.3 metric tons of CO_2 and other polluting gases into the atmosphere. The economic savings reach 83% with respect the diesel consumption. The methodology is suitable for aiding municipalities in identifying adequate bus lines to start this shift. Its application is feasible in any city since it requires as input data: the technical characteristics of electric and combustion buses, operational details of existing routes, and the number of passengers per route. Furthermore, this tool provides a means to calculate the present fuel costs, emission of CO_2 for each bus line, and the estimated electricity costs. © 2021 Elsevier Ltd

Author keywords

Buses; CO_2 emissions; Electric vehicle; Multi-criteria technique; Route prioritization; Sustainable transportation

1 Grijalva, E.R., López Martínez, J.M.

Analysis of the reduction of CO 2 emissions in urban environments by replacing conventional city buses by electric bus fleets: Spain case study (Open Access)

(2019) *Energies*, 12 (3), art. no. 525. Cited 23 times.
https://www.mdpi.com/1996-1073/12/3
doi: 10.3390/en12030525

View at Publisher

2 Hamurcu, M., Eren, T.

Strategic planning based on sustainability for urban transportation: An application to decision-making (Open Access)

(2020) *Sustainability (Switzerland)*, 12 (9), art. no. 3589. Cited 21 times.
https://www.mdpi.com/2071-1050/12/9/3589
doi: 10.3390/SU12093589

View at Publisher

3 Bravo-Moncayo, L., Lucio Naranjo, J., Pavón García, I., Mosquera, R.

Neural based contingent valuation of road traffic noise

(2017) *Transportation Research Part D: Transport and Environment*, 50, pp. 26-39. Cited 11 times.
www.elsevier.com/inca/publications/store/3/1/1/5/3/
doi: 10.1016/j.trd.2016.10.020

View at Publisher

4 Csuzi, I., Csuzi, B.

The urban electric bus, a sustainable solution to increase energy efficiency of public transport and reduce atmospheric pollution in the cities

(2017) *2017 Electric Vehicles International Conference, EV 2017*, 2017-January, pp. 1-6. Cited 4 times.
ISBN: 978-153862382-4
doi: 10.1109/EV.2017.8242101

View at Publisher

5 González-Rodríguez, M.S., Clairand, J.-M., Soto-Espinosa, K., Jaramillo-Fuelantala, J., Escrivá-Escrivá, G.

Urban traffic flow mapping of an andean capital: Quito, Ecuador (Open Access)

(2020) *IEEE Access*, 8, art. no. 3033518, pp. 195459-195471. Cited 4 times.
http://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=6287639
doi: 10.1109/ACCESS.2020.3033518

View at Publisher

6 Torabi, S., Bellone, M., Wahde, M.

Energy minimization for an electric bus using a genetic algorithm (Open Access)

(2020) *European Transport Research Review*, 12 (1), art. no. 2. Cited 8 times.
http://www.springer.com/engineering/mechanical+eng/journal/12544
doi: 10.1186/s12544-019-0393-1

View at Publisher

7 Ríos, A., Vargas, C., Guamán, J., Otorongo, M.

Comparative analysis of the energy consumption, economic cost and environmental impact between fossil and electric buses in the public urban transportation of the City of Ambato, Ecuador

(2019) *International Journal of Renewable Energy Research*, 9 (2), pp. 944-959. Cited 2 times.
www.ijrer.org

8 Woo, J., Choi, H., Ahn, J.

Well-to-wheel analysis of greenhouse gas emissions for electric vehicles based on electricity generation mix: A global perspective

(2017) *Transportation Research Part D: Transport and Environment*, 51, pp. 340-350. Cited 105 times.
www.elsevier.com/inca/publications/store/3/1/1/5/3/
doi: 10.1016/j.trd.2017.01.005

View at Publisher

9 Dong, J., Liu, C., Lin, Z.

Charging infrastructure planning for promoting battery electric vehicles: An activity-based approach using multiday travel data (Open Access)

(2014) *Transportation Research Part C: Emerging Technologies*, 38, pp. 44-55. Cited 335 times.
www.elsevier.com/inca/publications/store/1/3/0/
doi: 10.1016/j.trc.2013.11.001

View at Publisher

10 Mainul Islam, M., Shareef, H., Mohamed, A.

Optimal location and sizing of fast charging stations for electric vehicles by incorporating traffic and power networks

(2018) *IET Intelligent Transport Systems*, 12 (8), pp. 947-957. Cited 34 times.
www.ietdl.org/IET-ITS
doi: 10.1049/iet-its.2018.5136

View at Publisher

11 Lucas, A., Bonavitacola, F., Kotsakis, E., Fulli, G.

Grid harmonic impact of multiple electric vehicle fast charging

(2015) *Electric Power Systems Research*, 127, pp. 13-21. Cited 73 times.
doi: 10.1016/j.epsr.2015.05.012

View at Publisher

12 Clairand, J.-M., Guerra-Terán, P., Serrano-Guerrero, X., González-Rodríguez, M., Escrivá-Escrivá, G.

Electric vehicles for public transportation in power systems: A review of methodologies (Open Access)

(2019) *Energies*, 12 (16), art. no. en12163114. Cited 20 times.
https://www.mdpi.com/1996-1073/12/16
doi: 10.3390/en12163114

View at Publisher

13 Pamuła, T., Pamuła, W.

Estimation of the energy consumption of battery electric buses for public transport networks using real-world data and deep learning (Open Access)

(2020) *Energies*, 13 (9), art. no. 2340. Cited 24 times.
https://www.mdpi.com/1996-1073/13/9/2340
doi: 10.3390/en13092340

View at Publisher

14 Onar, S.C., Oztaysi, B., Otay, I., Kahraman, C.
Multi-expert wind energy technology selection using interval-valued intuitionistic fuzzy sets

(2015) *Energy*, Part 1 90, pp. 274-285. Cited 112 times.
www.elsevier.com/inca/publications/store/4/8/3/
doi: 10.1016/j.energy.2015.06.086

View at Publisher

15 (2021) *BYD, bus eléctrico K11A*
https://bydelectrico.com/ec/portfolio/bus-electrico-k11a/

16 Rupp, M., Handschuh, N., Rieke, C., Kuperjans, I.
Contribution of country-specific electricity mix and charging time to environmental impact of battery electric vehicles: A case study of electric buses in Germany

(2019) *Applied Energy*, 237, pp. 618-634. Cited 44 times.
http://www.elsevier.com/inca/publications/store/4/0/5/8/9/1/index.htt
doi: 10.1016/j.apenergy.2019.01.059

View at Publisher

17 Mohamed, M., Farag, H., El-Taweel, N., Ferguson, M.
Simulation of electric buses on a full transit network: Operational feasibility and grid impact analysis

(2017) *Electric Power Systems Research*, 142, pp. 163-175. Cited 73 times.
doi: 10.1016/j.epsr.2016.09.032

View at Publisher

18 Bak, D.-B., Bak, J.-S., Kim, S.-Y.
Strategies for implementing public service electric bus lines by charging type in Daegu Metropolitan City, South Korea (Open Access)

(2018) *Sustainability (Switzerland)*, 10 (10), art. no. 3386. Cited 14 times.
http://www.mdpi.com/2071-1050/10/10/3386/pdf
doi: 10.3390/su10103386

View at Publisher

19 República del Ecuador
(2019) *Ley Orgánica de Eficiencia Energética*. Cited 5 times.
Asamblea Nacional
https://www.recursosyenergia.gob.ec/wp-content/uploads/downloads/2019/03/Ley-Eficiencia-Energe%CC%81tica.pdf

20 Ministerio de Energía y Recursos Naturales No Renovables
Balance Energético Nacional
(2019) . Cited 262 times.
Ministerio de Energía y Recursos Naturales No Renovables Tech. rep., Quito, Ecuador (2019)
https://www.recursosyenergia.gob.ec/wp-content/uploads/2020/12/Balance-Energetico-Nacional-2019-1.pdf

21 Harris, A., Soban, D., Smyth, B.M., Best, R.

Assessing life cycle impacts and the risk and uncertainty of alternative bus technologies (Open Access)

(2018) *Renewable and Sustainable Energy Reviews*, 97, pp. 569-579. Cited 21 times.
doi: 10.1016/j.rser.2018.08.045

View at Publisher

22 Logan, K.G., Nelson, J.D., Hastings, A.

Electric and hydrogen buses: Shifting from conventionally fuelled cars in the UK (Open Access)

(2020) *Transportation Research Part D: Transport and Environment*, 85, art. no. 102350. Cited 34 times.
www.elsevier.com/inca/publications/store/3/1/1/5/3/
doi: 10.1016/j.trd.2020.102350

View at Publisher

23 Li, W., Li, Y., Deng, H., Bao, L.

Planning of electric public transport system under battery swap mode (Open Access)

(2018) *Sustainability (Switzerland)*, 10 (7), art. no. 2528. Cited 21 times.
http://www.mdpi.com/2071-1050/10/7/2528/pdf
doi: 10.3390/su10072528

View at Publisher

24 Rogge, M., Wollny, S., Sauer, D.U.

Fast charging battery buses for the electrification of urban public transport-A feasibility study focusing on charging infrastructure and energy storage requirements (Open Access)

(2015) *Energies*, 8 (5), pp. 4587-4606. Cited 119 times.
http://www.mdpi.com/1996-1073/8/5/4587/pdf
doi: 10.3390/en8054587

View at Publisher

25 Wang, J., Kang, L., Liu, Y.

Optimal scheduling for electric bus fleets based on dynamic programming approach by considering battery capacity fade

(2020) *Renewable and Sustainable Energy Reviews*, 130, art. no. 109978. Cited 19 times.
https://www.journals.elsevier.com/renewable-and-sustainable-energy-reviews
doi: 10.1016/j.rser.2020.109978

View at Publisher

26 Clairand, J.-M., Rodríguez-García, J., Álvarez-Bel, C.

Electric vehicle charging strategy for isolated systems with high penetration of renewable generation (Open Access)

(2018) *Energies*, 11 (11), art. no. en11113188. Cited 20 times.
https://www.mdpi.com/1996-1073/11/11
doi: 10.3390/en11113188

View at Publisher

27 Wu, Z., Guo, F., Polak, J., Strbac, G.
Evaluating grid-interactive electric bus operation and demand response with load management tariff

(2019) *Applied Energy*, 255, art. no. 113798. Cited 13 times.
https://www.journals.elsevier.com/applied-energy
doi: 10.1016/j.apenergy.2019.113798

View at Publisher

28 Clairand, J.-M., Gonzalez-Roriguez, M., Teran, P.G., Cedenno, I., Escriva-Escriva, G.
The impact of charging electric buses on the power grid

(2020) *IEEE Power and Energy Society General Meeting*, 2020-August, art. no. 9282014. Cited 4 times.
http://ieeexplore.ieee.org/xpl/conferences.jsp
ISBN: 978-172815508-1
doi: 10.1109/PESGM41954.2020.9282014

View at Publisher

29 Barragán-Escandón, E.A., Zalamea-León, E.F., Terrados-Cepeda, J., Vanegas-Peralta, P.F.
Energy self-supply estimation in intermediate cities
(Open Access)

(2020) *Renewable and Sustainable Energy Reviews*, 129, art. no. 109913. Cited 4 times.
https://www.journals.elsevier.com/renewable-and-sustainable-energy-reviews
doi: 10.1016/j.rser.2020.109913

View at Publisher

30 EMOV
EMOV, Inventario de emisiones atmosféricas del cantón Cuenca
(2014) . Cited 10 times.
EMOV Tech. rep., Cuenca, Ecuador

31 (2014) *BID, Cuenca, ciudad sostenible: Plan de Acción*. Cited 3 times.

32 Navigation, A.
Wgs 84 implementation
(1998) . Cited 2 times.

33 Luzuriaga, W.
Estimación de la energía requerida para la sustitución de la flota de autobuses públicos por autobuses eléctricos de la ciudad de Cuenca
(2019)
B.s. thesis Universidad de Cuenca

34 Wikner, E., Thiringer, T.
Extending battery lifetime by avoiding high SOC (Open Access)

(2018) *Applied Sciences (Switzerland)*, 8 (10), art. no. 1825. Cited 56 times.
https://www.mdpi.com/2076-3417/8/10/1825/pdf
doi: 10.3390/app8101825

View at Publisher

35 Wang, J.-J., Jing, Y.-Y., Zhang, C.-F., Zhao, J.-H.
Review on multi-criteria decision analysis aid in sustainable energy decision-making

(2009) *Renewable and Sustainable Energy Reviews*, 13 (9), pp. 2263-2278. Cited 1323 times.
doi: 10.1016/j.rser.2009.06.021

View at Publisher

36 Joshi, A., Kale, S., Chandel, S., Pal, D.K.
Likert scale: explored and explained
(2015) *Curr J Appl Sci Technol*, pp. 396-403. Cited 512 times.

37 (2014) *GAD Municipal de Cuenca, Plan de ordenamiento urbano de Cuenca*

38 GAD Municipal de Cuenca, Ciudades intermedias, crecimiento y renovación urbana
(2015) *Thematic meeting, intermediate cities, Cuenca*, p. 27.

39 Barragán-Escandón, A.
El autoabastecimiento energético en los países en vías de desarrollo en el marco del metabolismo urbano: caso Cuenca, Ecuador
(2018) . Cited 2 times.
Ph.D. thesis Universidad de Jaen

40 Ministerio de Coordinación de los Sectores Estratégicos
Balance energético nacional 2016, año base 2015
(2015)
Ministerio de Coordinación de los Sectores Estratégicos
https://issuu.com/sectoresestrategicos/docs/balance_energe__tico_2016

41 (2015) *EMOV EP, Inventario de emisiones atmosféricas del cantón Cuenca*, p. 2014. Cited 10 times.

42 (2009) *CGA, Resumen del inventario de emisiones atmosféricas del cantón Cuenca, año base 2007*

43 Muevecela, W.
Diseño del Sistema Eléctrico en Baja Tensión para Estaciones de Carga en Autobuses Eléctricos
(2018)
Univ. Cuenca

44 Hamurcu, M., Eren, T.
An application of multicriteria decision-making for the evaluation of alternative monorail routes (Open Access)

(2018) *Mathematics*, 7 (1), art. no. 16. Cited 23 times.
https://www.mdpi.com/2227-7390/7/1/16/pdf
doi: 10.3390/math7010016

View at Publisher

45 Álvarez León, J.C., Calle Erráez, D.F.
Determinación del costo operativo para el transporte de Pasajeros en el Bus-Tipo, en el sector urbano de la ciudad de Cuenca, con base en es nuevo sistema integrado de transporte
(2014)
Ph.D. thesis Universidad Politécnica Salesiana

46 Joubert, J.W.
Multi-agent model of route choice when vehicles are sensitive to road grade (Open Access)

(2017) *Procedia Computer Science*, 109, pp. 869-874. Cited 4 times.
http://www.sciencedirect.com/science/journal/18770509
doi: 10.1016/j.procs.2017.05.402

View at Publisher

47 Nassereddine, M., Eskandari, H.
An integrated MCDM approach to evaluate public transportation systems in Tehran (Open Access)

(2017) *Transportation Research Part A: Policy and Practice*, 106, pp. 427-439. Cited 56 times.
www.elsevier.com/inca/publications/store/5/4/7/
doi: 10.1016/j.tra.2017.10.013

View at Publisher

48 Hadas, Y., Nahum, O.E.
Urban bus network of priority lanes: A combined multi-objective, multi-criteria and group decision-making approach

(2016) *Transport Policy*, 52, pp. 186-196. Cited 19 times.
http://www.journals.elsevier.com/transport-policy/
doi: 10.1016/j.tranpol.2016.08.006

View at Publisher

49 González, L.G., Cordero-Moreno, D., Espinoza, J.L.

Public transportation with electric traction: Experiences and challenges in an Andean city (Open Access)

(2021) *Renewable and Sustainable Energy Reviews*, 141, art. no. 110768. Cited 2 times.
https://www.journals.elsevier.com/renewable-and-sustainable-energy-reviews
doi: 10.1016/j.rser.2021.110768

View at Publisher

50 Lopez-Ibarra, J.A., Milo, A., Gaztanaga, H., Herrera, V.I., Camblong, H.

Bus-to-route and route-to-bus approaches in hybrid electric buses fleet for battery lifetime extension

(2019) *2019 14th International Conference on Ecological Vehicles and Renewable Energies, EVER 2019*, art. no. 8813543. Cited 3 times.
http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=8798485
ISBN: 978-172813703-2
doi: 10.1109/EVER.2019.8813543

View at Publisher

51 Kivekas, K., Vepsalainen, J., Tammi, K.

Stochastic Driving Cycle Synthesis for Analyzing the Energy Consumption of a Battery Electric Bus (Open Access)

(2018) *IEEE Access*, 6, art. no. 8468964, pp. 55586-55598. Cited 31 times.
http://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=6287639
doi: 10.1109/ACCESS.2018.2871574

View at Publisher

52 Rahaman, M.S., Mei, Y., Hamilton, M., Salim, F.D.

CAPRA: A contour-based accessible path routing algorithm (Open Access)

(2017) *Information Sciences*, 385-386, pp. 157-173. Cited 33 times.
http://www.journals.elsevier.com/information-sciences/
doi: 10.1016/j.ins.2016.12.041

View at Publisher

53 Yildirim, V., Bediroglu, S.

A geographic information system-based model for economical and eco-friendly high-speed railway route determination using analytic hierarchy process and least-cost-path analysis

(2019) *Expert Systems*, 36 (3), art. no. e12376. Cited 11 times.
http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1468-0394
doi: 10.1111/exsy.12376

View at Publisher

54 Büyüközkan, G., Güleryüz, S.

A new GDM based AHP framework with linguistic interval fuzzy preference relations for renewable energy planning

(2014) *Journal of Intelligent and Fuzzy Systems*, 27 (6), pp. 3181-3195. Cited 26 times.
http://iospress.metapress.com/content/300180/
doi: 10.3233/IFS-141275

View at Publisher

Clairand, J.-M.; Facultad de Ingeniería y Ciencias Aplicadas, Universidad de las Américas, José Queri, Quito, Ecuador; email:jean.clairand@udla.edu.ec

About Scopus

What is Scopus

Content coverage

Scopus blog

Scopus API

Privacy matters

Language

日本語に切り替える

切换到简体中文

切換到繁體中文

Русский язык

Customer Service

Help

Tutorials

Contact us

ELSEVIER