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Natural gas trucks: a blue corridor project for the São Paulo state

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RESUMO

Este trabalho é um estudo inicial para a implementação de um Corredor Azul no Estado de São Paulo. Corredores Azuis são rotas que visam viabilizar o uso de gás natural liquefeito (LNG) para veículos pesados. O artigo discute os aspectos do gás natural como combustível, detalha o conceito de Corredores Azuis e debate questões da infraestrutura para a instalação de postos de abastecimento. Foram desenvolvidos mapas do Corredor proposto, cujos pontos de abastecimento foram estabelecidos segundo critérios de acesso aos gasodutos e fluxos nas principais rodovias do Estado. Os resultados apontam para significativa redução no consumo de óleo diesel e de emissão de CO2. Por fim, concluiu-se que apesar dos ganhos econômicos que podem ser proporcionados pelo uso de LNG, ainda assim seriam necessárias políticas públicas para aumentar a competitividade do gás natural em relação ao óleo diesel.

Palavras-chave: Corredores Azuis, Gás Natural Liquefeito,

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ABSTRACT

This work is an initial study for the implementation of a Blue Corridor in the State of São Paulo. Blue corridors are routes that aim to enable the use of liquefied natural gas (LNG) for heavy vehicles. The article discusses the aspects of natural gas as a fuel, it details the concept of Blue Corridors and the debates issues for refuelling stations installment. We developed maps for the proposed Corridor, in which access to gas pipelines and main highways traffic were the criteria to refueling points placement in the State. The results have shown reduction of diesel oil consumption and CO2 emission. Finally, it was concluded that in spite of the economic gains that can be provided by the use of LNG, public policies would still be necessary to increase the competitiveness of natural gas in relation to diesel oil.

Keywords: Blue Corridors, Liquefied Natural Gas,

2007). The adoption natural gas vehicle use depends on the existence of infrastructure, especially of supply pipelines. Natural gas vehicular technology is consolidated, competitively priced and large manufacturers already produce natural gas trucks in Brazil (source?). This study will focus on the use of natural gas in its liquid state (Liquified Natural Gas, LNG), since literature review has shown that it is more suitable for intercity road transport (Lebrato and Ribas, 2012).

For this study, we must consider the aspects related to public policy issues (D'Agosto et al., 2012; Moutinho dos Santos et al., 2013; Oliveira Filho, 2006; Peregrino et al., 2001). For example, the 'social cost' of external energy dependence has great relevance, since Brazil expenditures on diesel imports have a large weight in the country's trade balance. In 2014, the imported volume of diesel oil corresponded to 8.7 billion dollars to import about 11.3 million m³ of fuel (ANP, 2015).

Therefore, this article will present, a Blue Corridor and LNG Infrastructure for São Paulo state through data collected and results obtained and represented by maps.

2. NATURAL GAS

Natural gas (NG) is a mixture of several hydrocarbon gases, including methane (between 70% and 90%), ethane, propane, butane and pentane, as well as carbon dioxide, nitrogen and hydrogen sulphide. The composition of natural gas can vary widely, depending on the gas field (IEA, 2011). The main advantages of natural gas as a vehicle fuel are its cleaner combustion, with reduced emissions of particulate matter (PM), sulphur oxides (SO) and nitrogen oxides (NO_x) (Galbieri et al., 2017; Hekkert et al., 2005; Kannan et al., 2007; Kumar et al., 2011; Osorio-Tejada et al., 2017; Stefana et al., 2016; Yeh, 2007), its low-noise (von Rosenstiel et al., 2015; Yeh, 2007), as well as reduction of GHG emissions throughout its life-cycle, with a 10% reduction in GHG emission in comparison to diesel fuel (Arteconi and Polonara, 2013). Thus, there is less emission of polluting gases and the formation of solid deposits, which increases the engine's lifetime (Peregrino et al., 2001).

Two technologies are available for the use of Natural Gas as a vehicle fuel: Compressed Natural Gas (CNG), and Liquefied Natural Gas (LNG). CNG is obtained simply by compressing natural gas to less than one percent of the volume it occupies at standard atmospheric pressure. LNG, on the other hand, is obtained by cooling

NG for removing impurities, such as water, nitrogen, carbon dioxide, hydrogen sulphide and other sulphur components. The removal of these components is carried out before the liquefaction process, since some may freeze at the gas dew point (ANP, 2010). Thus, by purifying the methane from its liquid 'impurities', LNG can be considered a cleaner fuel. The average regular NG and LNG compositions are shown in Figure 1.

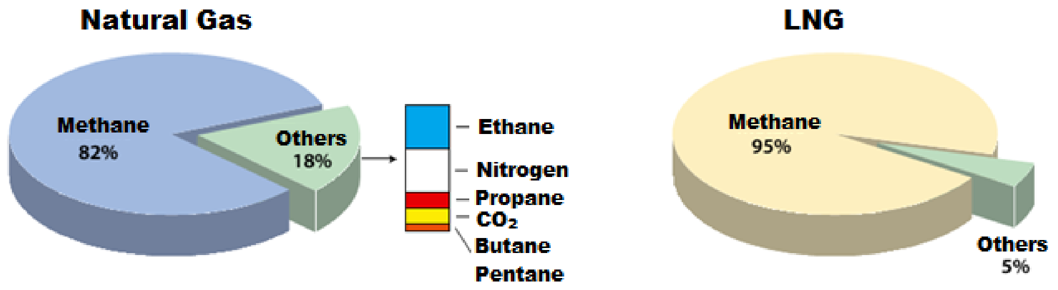

Figure 1: Typical composition of natural gas and LNG (adapted from ANP, 2010).

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NG heavy-duty vehicles already comply with Euro V emission standards and have potential to reach future Euro VI emission standards without complex exhaust gas after-treatment technologies which have increased installation and maintenance costs. NG vehicles typically cost more than gasoline or diesel vehicles. This is largely due to the cost of high-pressure and insulated fuel tanks, which are necessary to store CNG or LNG. However, the cost of natural gas itself is lower compared to diesel oil. The savings in fuel costs can translate into significant savings over the life of a vehicle, depending on fuel efficiency and distance driven. The greatest savings are currently being seen in heavy-duty, high mileage fleets. These vehicles consume enough fuel for owners and operators to see a pay back in as little as 18–24 months. As the price of fuel tanks comes down, light-duty passenger vehicles will become less expensive and also will enjoy a shorter payback period (NGV America, 2018).

3. BLUE CORRIDOR

Blue Corridors are routes for road transport (usually trucks) that use compressed (CNG) or liquefied (LNG) natural gas as motor fuel. The main feasibility factor for Blue Corridor is the existence of gas stations, in order to encourage the use of natural gas vehicles, breaking the vicious "chicken and egg" cycle. The study that first proposed a Blue Corridor (UNECE, 2003) has defined this concept and proposed some routes. The document 'Blue Corridor Project', was developed by a working group from the Gas Inland Transport Committee of the European Commission for Economy (ECE). It presented some Blue Corridors initiatives in the European territory based on CNG.

In the case of heavy duty vehicles (HDV) specifically, the required infrastructure depended on the vehicle's purpose: passenger or freight transport, urban or road. A LNG refuelling network for goods transport would need to be developed together with companies and truck operators in order to be installed near terminals. Hence, the European Blue Corridor project has now acquired a new perspective. Rather than promoting CNG, which required refuelling station every 100 km, it is now the first initiative in that continent that recognizes that LNG is the most indicated fuel for road transport. By following this pathway, they now seek to promote an appropriate and standardized LNG development.

3.1 LNG Infrastructure

There is a variety of different filling station configurations, which can be conceived in permanent or mobile arrangements. They can dispense gas exclusively in either liquid or gaseous form (Type A) or both (L-CNG Stations – Type B). According to Baux et al., (2013), the LNG refuelling system, using a liquid natural gas storage tank, allows refuelling of liquefied gas at pressures up to 20 bar. A LNG station is mainly composed of a vaporizer, an LNG tank and a dispenser. Some stations operate without a LNG cryogenic pump which implies a slightly lower flow rate and sometimes a higher storage pressure (around 12 bar compared to 3 or 8 bar). LNG is delivered at different pressures according to the truck manufacturer, which may be 3, 8 or 18 bar.

The ideal setup for each investor ultimately depends on current and predicted demand for LNG and on the status of the technology in each country. Countries that already have a sizeable fleet of LNG trucks and offer some LNG refuelling infrastructure have already established travel routes and traffic patterns, making it easier to determine a viable location for a permanent station (Baux et al., 2013).

The State of São Paulo has a total of 3772 kilometres of gas pipelines, with diameters that varies from 14 to 28 inches (Petrobras, 2017). The main pipeline, Gasbol, which is how Bolivian gas is imported to Brazil, corresponds to about 60% of the State's transmission network. Its north stretch, that crosses the State from West to East ends in the Metropolitan Region of São Paulo. Its south stretch, which starts in Paulinia (Campinas Region), supply São Paulo and Brazil's southern regions. Three concessionaires operate more than 17 thousand kilometres of local distribution network in a total of 148 municipalities. However, most of this network is concentrated in Comgas' concession area, which comprises the administrative regions of São Paulo, São José dos Campos, Santos and Campinas (ARSESP, 2017). A total of 469 stations serve CNG for vehicles and most of them are also concentrated in Comgas' area.

4. DATA AND METHODS

To perform this work, we use two methods: cartography (elaboration and use of maps), and quantitative (data collection, analysis and inserted in maps). For the cartography method was used the geoprocessing techniques through GIS program - defined as systems constituted by a set of computational programs which integrates spatially referenced data to a known coordinate system, aiming to collect, store, retrieve, manipulate, view and analyse these data (Fitz, 2008). For the elaboration of the maps, we use the following sources: the Brazilian Institute of Geography and Statistics (IBGE, 2017) regarding the geographical intermediate regions of the State of São Paulo; the Ministry of Transport, Ports and Aviation (MTPA, 2016) and the Department of Roads and Traffic from São Paulo's Secretary of Logistics and Transport (DER, 2016) for toll and road data, and; the Energy Research Company (EPE, 2016).

For the quantitative analysis, the study used literature review and cargo transportation data from open government databases or obtained directly from the responsible institution. São Paulo State is divided into 645 municipalities and its corresponding total area is 248 222,362 km² which presents expressive territorial inequalities. For this reason, Egler, Bessa, and Gonçalves (2013) understand São Paulo State's territory as a polycentric and diversified region oriented towards the capital, a global metropolis. Regarding this policentrality, São Paulo's network is complex and hierarchical, as well as strongly polarized by the Paulistan metropolis. Important regional capitals, such as Campinas, Ribeirão Preto and São José do Rio Preto represent nodes of this policentrality.

This study has adopted Table 1's assumptions for defining the LNG refuelling stations placement. It sought to maximize coverage area for liquefied natural gas trucks by following the State's needs on haulage transportation and main production drain channels. All maps produced in this study divide São Paulo into ten Administrative Regions, which are then divided into intermediate regions that involve Main Cities (Regional Capitals) influence area. Intermediate Geographic Regions correspond to an intermediate scale between the Units of the Federation and the Geographic Immediate Regions, organizing the territory by private and public flows of management, and also by urban functions of high complexity (IBGE, 2017).

Table 1: Blue Corridor's Assumptions

Assumption	Description
A	Stations must be located in main roads in order to minimize demand risks;
B	Stations must be located as near as possible to the main pipelines in order to secure NG supply, respecting assumption A;
C	Stations' dispositions must allow production drain from the State's extreme (farthest regions from the Capital) to the centre and the to sea coast, where the Port of Santos is located, respecting assumptions A and B;
D	The capital must have at least one refuelling station in order to allow return to the extremities;
E	To maximize the State's covered area with a maximum of one station, respecting assumptions A through D;

Figure 2 presents where natural gas pipelines cross main highways in the State of São Paulo. These junctions were represented with a yellow dot and fulfil assumptions A and B (Table 1). A total of 30 junctions were identified which are highly concentrated in the macro-metropolitan area (around São Paulo and Campinas administrative regions), thus justifying assumption D. However we had to check where the vehicle flux was most relevant in order to suggest refuelling places (assumption C). This suggestion was heuristically determined.

Once the locations were defined, we estimated the whole Blue Corridor coverage (assumption E) by drawing a circle centred on these places, with a radius of 241 kilometres. These values represent half of the truck's autonomy reported in (HARTOUNIAN; ROCHE, 2008), the lowest autonomy found in the literature, representing a conservative distance from the fueling station and back (half of the autonomy represents a round trip).

Figure 2: Highways and Natural Gas Pipelines Junctions in the State of São Paulo (self-elaboration)

Figure 3 summarizes daily traffic flow from the State's Main Cities to São Paulo City and served as a basis for assumption C.

Flow of vehicles from major cities to São Paulo

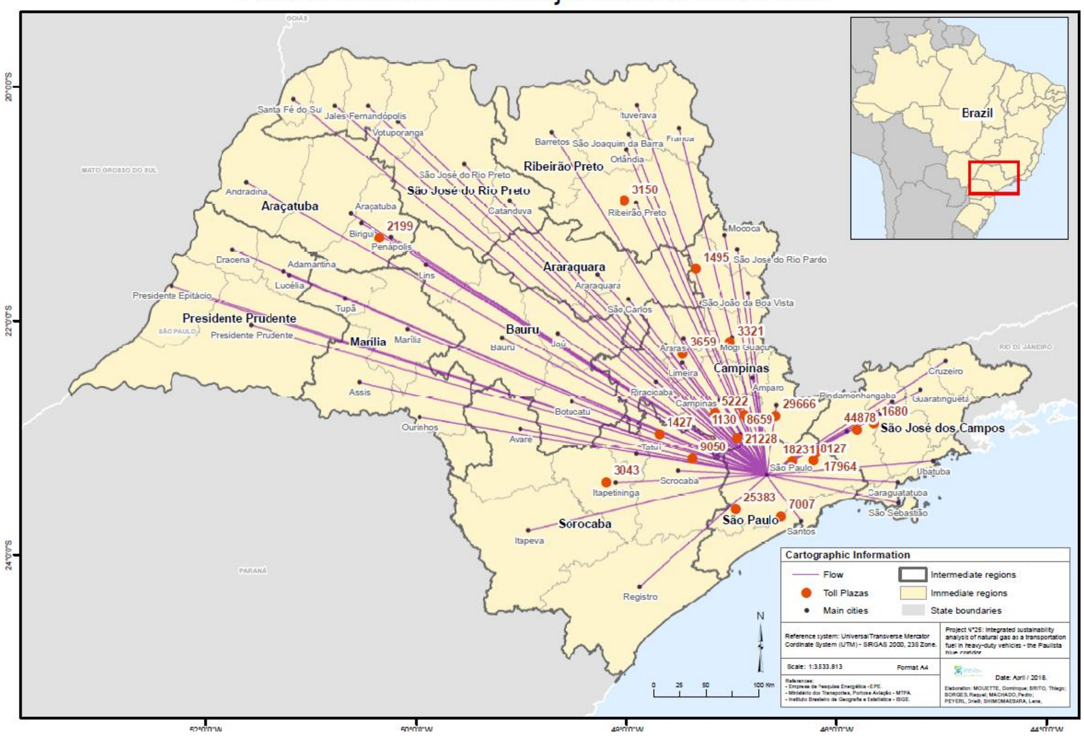

Figure 3: Traffic Flow from Main Cities to the Capitol (self-elaboration)

Data from tolls show the flux of commercial vehicles in the state. Data shows a concentric flux of commercial vehicles from the state extremities towards the state Capital, São Paulo. Since this study is focused on Heavy Duty Vehicles (HDV), an average percentage of 75% was considered as the share of HDV in the total commercial fleet, based on data from the National Traffic Survey, done by the National Department of Transport Infrastructure.

5. RESULTS AND DISCUSSION

Figure 4 shows the optimal location of LNG refuelling stations, constrained by Table 1's assumptions. The daily flux of trucks through the routes presented in this map accounts for 82.940 vehicles every day. By current prices, the LNG refuelling stations required to attend this capacity would require an investment in infrastructure (fueling stations) of 39 billion US$, according to capital costs in Mariani (2016). A total of 830 tons of LNG would substitute 1.143.538 litres of diesel oil daily. This substitution could mitigate up to 1.4 thousand tons of CO_2 equivalent.

Figure 4: Blue Corridor with Suggested Refuelling Stations and coverage area (self-elaboration)

Also as shown by Figure 4, in case these seven locations provide LNG refuelling, the Blue Corridor would cover almost the entire State of São Paulo. The coverage radius of some locations reach even small portions of its neighbor States Minas Gerais, Rio de Janeiro, Paraná and Mato Grosso do Sul. It is important to note that we have used a conservative value for the circle's radius (241 km). Studies such as (TIMMERMANS, 2016) and (SMITH; WEST; GONZALES, 2014) report higher autonomy for LNG trucks of 650 and 563 km, respectively.

6. CONCLUSIONS

This article sought to provide a tool to help policy makers to have a broader view of how a Blue Corridor for LNG trucks could be developed and operated. The substitution of a portion of diesel oil used in cargo transportation sector can reduce emissions that are harmful to the human health and that contribute to global change, as shown by our results. Besides that, it could provide economic savings (since natural gas is cheaper) and improve Brazil energy security, since most of the diesel oil consumed in country is imported.

However, it is necessary to overcome the chicken-egg dilemma by focusing first on early adopters. The Massachusetts Institute of Technology (MIT, 2011, *apud* ROSENSTIEL et al., 2014) sees an appropriate early market in hub-to-hub transportation of goods, which uses 20 % of long-haul diesel fuel consumption in the USA. These considerations together with our analysis reinforces the need for a strategic plan, which includes public policy to promote the use of LNG, in order to ensure investments security in the long term. The beneficiaries of such policies are the stakeholders related to heavy-duty truck operation and truck or bus fleet; private and municipal energy utilities (wholesale and retail); and vehicle and engine manufacturer. The greatest challenges for the use of LNG are to secure the ready acceptance by the public and the production of safe systems to generate, store, distribute and consume. So to use LNG as an alternate source of energy requires modification in existing technology, development of more infrastructure and public awareness about this fuel. Future studies regarding this issue will include an integrated analysis with non pipelines supply to refuelling stations, such as from truck and ship carries (without going through the regasification process. Interviews and questionnaires to fleet owners and truck drivers will also detect their acceptance to LNG. Finally, a diffusion study will estimate the time required to achieve a viable Blue Corridor.

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REFERENCES

ANP, 2015. Brazilian Statistical Yearbook of Petroleum, Natural Gas and Biofuels 2015. Rio de Janeiro.

ANP, 2010. Liquefied Natural Gas in Brazil: ANP Experience in the implementation of LNG importation projects, 4th ed. National Agency for Petroleum, Natural Gas and Biofuels, Rio de Janeiro.

ARSESP, 2017. Gás Canalizado [WWW Document]. URL http://www.arsesp.sp.gov.br/SitePages/gas-canalizado/informacoes-tecnicas.aspx (accessed 2.2.BC).

Arteconi, a., Polonara, F., 2013. LNG as vehicle fuel and the problem of supply: The Italian case study. Energy Policy 62, 503–512. doi:10.1016/j.enpol.2013.08.016

Baux, Y., Porto, M.R., Ribas, X., 2013. LNG-BC D3.1 - state of LNG and LCNG filling stations technologies in Europe.

D'Agosto, M.D.A., Souza, C.D.R. De, Silva, S.D., Barboza, A.P., Almeida, M.L.R. De, 2012. Technological Alternatives for bus in Rio de Janeiro. Rio de Janeiro.

Egler, C.A.G., Bessa, V. de C., Gonçalves, A. de F., 2013. Dinâmica territorial e seus rebatimentos na organização regional do estado de São Paulo. Confins 19. doi:10.4000/confins.8602

EMS, 2017. Energy Balance of the State of São Paulo. São Paulo.

EPE, 2016. Infraestrutura dos Gasodutos no Brasil. Disponível em: http://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-169/Mapa%20da%20Infraestrutura%20de%20Gasodutos%20de%20Transporte.pdf. Acesso em 14 de Maio de 2018

EPE, 2017. Brazilian Energy Balance 2017: Base Year 2016. Brasilia.

Galbieri, R., Brito, T.L.F., Mouette, D., de Medeiros Costa, H.K., Moutinho dos Santos, E., Fagá, M.T.W., 2017. Bus fleet emissions: new strategies for mitigation by adopting natural gas. Mitig. Adapt. Strateg. Glob. Chang. 23. doi:10.1007/s11027-017-9771-y

Hartounian, S., & Roche, G. (2008). How far can you go in an LNG truck ? How about to Boron and back — with fuel to spare ? Boron.

Hekkert, M.P., Hendriks, F.H.J.F., Faaij, a. P.C., Neelis, M.L., 2005. Natural gas as an alternative to crude oil in automotive fuel chains well-to-wheel analysis and transition strategy development. Energy Policy 33, 579–594. doi:10.1016/j.enpol.2003.08.018

IBGE (2017). Instituto Brasileiro de Geografia e Estatística. Divisão Regional do Brasil. Coordenação de Geografia. Rio de Janeiro: IBGE, 2017.

IEA, 2011. World Energy Outlook Special Report: Are we Entering the Golden Age of Gas? doi:10.1049/ep.1977.0180

IPCC, 2014. Transport, in: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kannan, R., Leong, K.C., Osman, R., Ho, H.K., 2007. Life cycle energy, emissions and cost inventory of power generation technologies in Singapore. Renew. Sustain. Energy Rev. 11, 702–715. doi:10.1016/j.rser.2005.05.004

Kumar, S., Kwon, H.T., Choi, K.H., Lim, W., Cho, J.H., Tak, K., Moon, I., 2011. LNG: An eco-friendly cryogenic fuel for sustainable development. Appl. Energy 88, 4264–4273. doi:10.1016/j.apenergy.2011.06.035

Lebrato, J., & Ribas, X. (2012). LNG Blue Corridors position paper.

Mariani, F. (2016). Cost analysis of LNG refuelling stations, (321592). Retrieved from http://lngbc.eu/system/files/deliverable_attachments/

Moutinho dos Santos, E., Galbieri, R., Brito, T., Fagá, M., Simões, A., 2013. Revisão do Conceito de Transporte Sustentál & Promoção do GNV na Estratégia de Substituição de Óleo Diesel no Transporte Urbano. São Paulo.

MTPA, 2017. Ministry of Transport, Ports and Aviation [WWW Document]. URL http://www.transportes.gov.br/ (accessed 10.18.17).

NGV America, 2018. Natural Gas Vehicles for America [WWW Document]. URL http://www.ngvamerica.org/ (accessed 2.16.18).

Oliveira Filho, A.D. de, 2006. Substitution of diesel for natural gas in buses in public urban transportation. Dissertation. University of São Paulo.

Osorio-Tejada, J.L., Llera-Sastresa, E., Scarpellini, S., 2017. Liquefied natural gas: Could it be a reliable option for road freight transport in the EU? Renew. Sustain. Energy Rev. 71, 785–795. doi:10.1016/j.rser.2016.12.104

Peregrino, F., Oliveira, L.B., Mattos, L.B. de, Sampaio, M.R., Cabral, S.D., 2001. Transporte Sustentável: alternativas para ônibus urbanos. COPPE - UFRJ, Rio de Janeiro.

Petrobras, 2017. São Paulo [WWW Document]. URL http://www.petrobras.com.br/pt/nossas-atividades/principais-operacoes/gasodutos/sao-paulo.htm (accessed 2.2.BC).

Stefana, E., Marciano, F., Alberti, M., 2016. Qualitative risk assessment of a Dual Fuel (LNG-Diesel) system for heavy-duty trucks. J. Loss Prev. Process Ind. 39, 39–58. doi:10.1016/j.jlp.2015.11.007

UNECE, 2003. Blue Corridor Project: on the use of natural gas a motor fuel in international freight and passenger traffic. New York and Geneva.

Von Rosenstiel, D.P., Heuermann, D.F., Hüsig, S., 2015. Why has the introduction of natural gas vehicles failed in Germany?—Lessons on the role of market failure in markets for alternative fuel vehicles. Energy Policy 78, 91–101. doi:10.1016/j.enpol.2014.12.022

Yeh, S., 2007. An empirical analysis on the adoption of alternative fuel vehicles: The case of natural gas vehicles. Energy Policy 35, 5865–5875. doi:10.1016/j.enpol.2007.06.012