Energy Efficiency measures for the road transportation of liquid fuels sector in Ecuador

J.P Diaz-Samaniego\textsuperscript{*1}, Patricio Gallardo\textsuperscript{*2}

\textsuperscript{*1}Instituto Nacional de Eficiencia Energética y Energías Renovables, Quito, Ecuador.

\textbf{Abstract} — The present paper aims to identify some recommendations or measures in order to achieve energy savings within the road transportation of liquid fuels sector in Ecuador. The recommendations that are addressed in this document are based on the results obtained after the execution of a Vehicle Routing Problem (VRP) Solver program, eco-driving measures and optimization fleet. Energy consumption is forecasted using LEAP (Long-range Energy Alternatives Planning System) software and energy savings are estimated upon comparing the reference scenario against three alternative scenarios that consider eco driving, fleet optimization and routing optimization. For this assessment was necessary to scope some indicators like: energy activity from transport fleet, energy intensity and fleet optimization target. Finally results indicate that apply VRP optimization is better option compared to eco-driving and fleet optimization. And applying all the measures together it can achieve cumulative savings around of 762,3 KBOE (kilo barrels oil equivalents) in whole analyzed period.

\textbf{Keywords} — Energy efficiency; Fuel consumption, Optimization; Freight Transport.

\textbf{I. INTRODUCTION}

The optimization of transport supply chains is one of the most important research subjects related with energy efficiency in transportation today. A correct design of a transport supply chain may reduce the transportation costs, and further decrease energy consumption and improve the efficiency of the goods delivery process [1]. Nowadays, the efforts that are being channeled towards the development of optimization models and methods are far more substantial than they were in the past [2].

In Ecuador, the transport sector is the most critical energy user. According to the 2015 Energy Balance, 46% of energy is consumed by the transportation sector, from which 86% is used by road transportation. Freight transportation alone consumed a total of 17.64 MBOE (Millions Barrels Oil Equivalent) in the year 2014 [3].

In case of fuel distribution, there exists a direct relationship between fuel demand and energy consumption, that is, the higher the fuel demand, the higher the need for larger storage capacities and fuel delivery trips. It is important to realize that a supply chain can be very complex and it does not only involve the road transportation of goods [1]. There are additional problems and areas that should also be accounted for, so as to diminish energy consumptions and mitigate Greenhouse Gas (GHG) emissions; thereby we have identified three main applicable measures for our case of study:

- Eco-driving programs.
- Fleet’s Capacity optimization.
- Vehicle routing optimization.

\textbf{A. Eco-driving programs}

Some studies reveal that Eco-driving measures can be very useful to reduce emissions and energy consumption [4]. Some of the advantages of this measure are: low cost implementation, reduction of travel costs, improved safety, reduced maintenance costs, emissions mitigation and conductors’ stress abatement. According to the bibliography, this programs have the potential to achieve 15% reduction in fuel usage [5]. There is not a consensus on the savings percentage, other studies have reported fuel consumption reductions of around 10% [6] and 4.6% [7], therefore the estimations are highly variable.

The complexity behind eco-driving programs relies on the need for a constant monitoring process since bad driving habits are recurrent. Other aspects to consider are related to staff turnovers in the transportation companies that imply the need to train the new crew of drivers [4]. In some transport hall transport departments like Calgary, Canada, there is an complete constantly monitoring program in petrol and hybrid vehicles, in this program have been reported “savings around 1.7 kg of CO$_2$ per vehicle per day and decreased average idling between 4% to 10%” [4].

\textbf{B. OPTIMIZATION OF THE FLEET’S CAPACITY}

In public transport, one of the best ways to reduce fuel consumption is to mobilize people using vehicles with larger passenger capacities, due to the intrinsic energy intensity that is characteristic to public transportation means. A similar approach applies for freight transportation, so that it is less energy intensive to transport goods in vehicle with
large capacities. For instance, the energy required to transport one gallon of fuel with a 10,000 tanker is less than the energy required to transport one gallon of fuel with a 6,000 gallon tanker. Under this alternative, it is also valid to consider the employment of vehicles with more efficient technologies.

According to previous evaluations five main capacity categories have been identified: 10,000, 6,000, 4,000, 2,000 and 1,000 gallons, and each category has a specific energy intensity index [8].

<table>
<thead>
<tr>
<th>Vehicle capacity</th>
<th>Energy Intensity [gallon used/gallon transported]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000 gallons trucks</td>
<td>0.0005</td>
</tr>
<tr>
<td>6,000 gallons trucks</td>
<td>0.0008</td>
</tr>
<tr>
<td>4,000 gallons trucks</td>
<td>0.0010</td>
</tr>
<tr>
<td>2,000 gallons trucks</td>
<td>0.0041</td>
</tr>
<tr>
<td>1,000 gallons trucks</td>
<td>0.0058</td>
</tr>
</tbody>
</table>

The energy intensities shown on Table I, are obtained from average specific fuel consumption rates and they do not necessarily consider other aspects like a speed, altitude, engine size and mileage.

C. VEHICLE ROUTING OPTIMIZATION

Nowadays, the implementation of optimization tools is becoming mandatory amongst enterprises worldwide [1]. There are some barriers associated to modeling, algorithmic and computational aspects of supply chain design and optimization. That is the modeling process should account for the scale of the problem and what issues need to be considered in the objective function, so that the optimization does not only consider a specific cost. Additionally, under the current global circumstances, mathematical models have the challenge to incorporate sustainability in the analysis. [1].

In Gallardo & León (2016), a program coded in R language, uses a combination of a branch and bound (BNB) and saving algorithms, in order to get an optimal/near optimal solution for the Capacitated Vehicle Routing Problem (CVRP). They execute the program for a network consisting of 39 petrol stations and a main terminal. The program carries out an optimization process in regards to a cost matrix depending on distance or cost. The fleet maximum capacity is also given and they incorporate a feature that allows a client node to be served by more than one vehicle in case the demand exceeds the vehicle capacity.

**OBJECTIVE**

Propose recommendations or measures for the reduction of energy consumption in transport of fuels. And to compare the effectiveness between efficient conduction, optimization of transport fleet capacity and a Vehicle Routing Problem (VRP)

**II. METHOD**

A. Fuel consumption and network activity

Energy use is appraised using LEAP software, given the activity of the sector [gal-km] and energy intensity indexes in regards to all the vehicle categories that are mentioned in Table 1. The year 2014 corresponds to the base year, and the activity of the sector was determined through the product between the gallons delivered and total distance travelled in that year. The activity for each fuel segment in the base year is shown in Table II.

**TABLE II**

<table>
<thead>
<tr>
<th>Fuel Distribution</th>
<th>Logistic Activity x10^9 [gal-km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Premium</td>
<td>59.85</td>
</tr>
<tr>
<td>Extra</td>
<td>52.36</td>
</tr>
<tr>
<td>Super</td>
<td>13.38</td>
</tr>
<tr>
<td>Etanol</td>
<td>2.31</td>
</tr>
</tbody>
</table>

The activity is forecasted up to the year 2030. The trend follows the behavior of population and gross domestic product projections. Hence the reference or business as usual (BAU) scenario follows an inertial tendency where: activity of diesel premium is growing at an annual rate of 5.3%, Extra is growing at a 7.8% rate, Super and Ethanol are growing at 6.1% and 7.8% respectively. See Figure 1.

![Fig. 1 BAU or Inertial energy activity of fuel distribution.](http://www.ijettjournal.org)

The BAU scenario lacks the implementation of any energy efficiency measure and given the trend it is estimated that final energy consumption in 2030
will be 186.6 thousand Barrels Oil Equivalent (BOE), see Figure 2.

Fig. 2 Reference (BAU) scenario energy fleet demand.

An area was created in LEAP and three scenarios are defined with respect to the aforementioned energy efficiency measures. In the eco driving scenario it is assumed that reductions will increase from zero up to 4.6% in 2030. This assumption considers a plausible and moderate behavior as reported in the scientific literature [4], [5], [7].

In the fleet optimization scenario, the activity associated to each category changes through time so that vehicles with larger capacities tend to be more involved in the future, so that the overall energy intensity is decreased in time. The behavior or participation from each category is summarized in Table III.

The third scenario conceives the optimization of the routes, so that the distance travelled in the delivery process is minimized. The VRP solver program is executed using historical data corresponding to deliveries that were carried out in the canton of Quito. It is assumed that the logistics in other cantons are similar and that the estimated savings can be assumed nationwide. The total distance traveled, trip duration and energy consumption are presented in Table IV for the real and optimal cases, where the first two rows correspond to an optimization carried out with respect to distance and time respectively; the third row correspond to the BAU case.

TABLE III

<table>
<thead>
<tr>
<th>Vehicle capacity</th>
<th>Today</th>
<th>In 2030</th>
</tr>
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<tbody>
<tr>
<td>10000 gallons trucks</td>
<td>34.74%</td>
<td>58.9%</td>
</tr>
<tr>
<td>6000 gallons trucks</td>
<td>30.41%</td>
<td>38.9%</td>
</tr>
<tr>
<td>4000 gallons trucks</td>
<td>30.12%</td>
<td>2.0%</td>
</tr>
<tr>
<td>2000 gallons trucks</td>
<td>4.56%</td>
<td>0.1%</td>
</tr>
<tr>
<td>1000 gallons trucks</td>
<td>0.16%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

TABLE IV

RESULTS OF VRP MODEL DISTRIBUTION.

<table>
<thead>
<tr>
<th>Case</th>
<th>Distance (km)</th>
<th>Time (min)</th>
<th>Energy consumption (gall diesel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total_Distance</td>
<td>2312.46</td>
<td>3043.57</td>
<td>315.27</td>
</tr>
<tr>
<td>Total_Time</td>
<td>2380.00</td>
<td>3058.60</td>
<td>320.19</td>
</tr>
<tr>
<td>Total_BAU</td>
<td>2395.66</td>
<td>3118.52</td>
<td>430.86</td>
</tr>
</tbody>
</table>

The optimal and BAU scenario are compared in order to obtain a factor that can be applied over the project activity of the reference scenario. The factor is calculated upon the formula shown in (Eq.1).

\[
\text{Factor reduction} = \frac{D_{VRP}}{D_{BAU}}
\]  

Where DVRP is distance travelled in the distance optimization case and DBAU is the distance travelled in the BAU case. For this computing factor reduction was 0.73.

III. RESULTS

Assuming that eco driving will imply a final reduction in energy consumption of 4.6% in the final year, it is estimated that the total savings in 2030 alone are 12 700 BOE. A comparison between the real and the eco driving scenario is shown in Figure 3.

Fig. 3 Energy consumption in Eco driving and reference scenarios.

The savings achieved for the whole period of analysis in regards to the Eco Driving scenario can be visualized in Figure 4.
A similar assessment was performed for the other two scenarios. In the scenario corresponding to the rearrangement of the fleet it is estimated that a total saving of 37,6 KBOE can be achieved in 2030, see Figure 5.

Energy savings for the whole period of analysis are shown in Figure 6. In the VRP implementation scenario a factor of 0.71 is applied over every point included in the activity trend of the reference scenario starting from the year 2015. In terms of energy savings this is the most attractive; only in 2030 total savings of around 54,1 KOEB can be achieved, see Figure 7.

All scenarios that were considered are exclusive of each other meaning that all three measures can be incorporated simultaneously, hence a fourth scenario considers a combination of all the proposed measures. According to the calculations we predict potential saving of around 86,8 KBOE in 2030 and cumulative savings for the whole period of around 762,3 KBOE, see Figure 9.

### IV. CONCLUSIONS

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Even though predicting future phenomena can be a very complex task, energy assessment tools can allow us to make better decisions that will help us to be aligned with desired objectives that are considered in the policy design process.

Eco-driving measures are more economic than other analyzed recommendations, however they do not represent substantial reductions in energy use and sometimes it is not possible to ensure long term effectiveness.

Fleet optimizations measures present better results than Eco-driving techniques, but these measures imply higher costs since they imply the need to make important investments associated to fleet renewal. Also having vehicles with higher capacities means that less trips will be required and consequently there will be fewer jobs. However the economic benefits can foster other programs that may enhance the productivity of the country and somehow soothe the economic drawbacks caused by the potential layoffs from this sector.

The VRP optimization recommendation is the most attractive in terms of energy savings. Also, the implementation of such measure does not require major investments and they can be replicated in other logistic chains that involve freight operations.

From an ideal perspective it will be highly desirable to have all measures implemented simultaneously as described in the combined scenario; however it will require more efforts in terms of policy development and economic investment. All measures are highly replicable and can be applied in other supply chains taking into account specific features that may inquire the need of additional constrains or factors.

V. REFERENCES