Abstract

Fuel consumption has always been a matter of economic concern in road fleet management, giving rise to many initiatives aimed at fostering more efficient energy use. The increasingly awareness of environmental problems now requires these programs to include environmental aspects. A structured Eco-efficiency Management Program (EEMP) is proposed for road fleet operation, taking into account the traditional approach that strives to minimise fuel consumption as well as wider economic and environmental aspects. The EEMP has its potential evaluated in a case study undertaken for INFRAERO, Brazilian’s airport authority, on the operation of its road fleet supporting aircraft ground operations at Rio de Janeiro International Airport. The paper looks at EEMP’s implementation by identifying the program’s phases, its participants and their competencies, eco-efficiency indicators, and performance targets. © 2004 Elsevier Ltd. All rights reserved.

Keywords: Atmospheric pollution; Eco-efficiency; Energy; Fuel savings; Road transport

1. Introduction

Although economic concern triggered a broad-based upsurge in energy-efficiency programs for road transport, considering the benefits on the reduction of fuel consumption (Walters, 1992; 1361-9209/$ - see front matter © 2004 Elsevier Ltd. All rights reserved. doi:10.1016/j.trd.2004.09.001
the implementation of those programs involves costs that are hardly accounted on a cost-benefit analysis. The increasingly widespread awareness of environmental problems demands that the same level of importance be assigned to economical and environmental impacts caused by the use of energy on road transport. The need to include environmental aspects in energy-efficiency programs is a crucial factor in attaining sustainability.

This paper proposes an improvement on energy-efficiency program for road fleet operation that takes into account both the traditional approach that strives to minimise fuel consumption, as well as economical and environmental aspects related to this activity, through the introduction of the concept of eco-efficiency.

2. Energy-efficiency programs for road transport

Transportation depends on the energy linked directly to vehicle movements (end use) and to energy linked indirectly to this movement (indirect use). The latter involves the energy embodied in roadway infrastructure (construction, conservation, maintenance and administration); vehicle (production, maintenance and disposal), and fuel supply (Organisation for Economic Co-operation and Development, 1997). In both cases, this energy can be accounted in two ways: gross energy and useful energy. Differences between them include the losses along the energy supply chain and end use (Rubin, 2001). Energy-efficiency programs for transport are usually limited to energy end use, where the heaviest efficiency losses are found—e.g., while the whole supply chain of gasoline and diesel oil has an average energy efficiency of 85% (Boustead and Hancock, 1979), road vehicles energy efficiency rates are between 10% and 25% (Poulton, 1997). End use energy efficiency is affected by three factors related to vehicles design; related to road infrastructure and related to operation (Walters, 1992).

Martins et al. (1999) present a selection of international experiences of energy-efficiency programs, including programs for road transport. Those programs commonly include vehicle design and operation, considering fuel efficiency targets, fuel reduction labels and fuel-efficient design and they also involve traffic control programs, drivers’ training, accurate fleet inspection and improved maintenance on vehicles. The implementation of such programs enables reductions in fuel consumption and associated operational costs considered as direct benefits. But the planning and maintenance of them involve additional costs not always considered, and a cost/benefit analysis is recommended to improve the economic aspect of such programs. Besides the economic aspect, to access an environmentally sustainable supplementary factor need to be considered and this requires the introduction of the concept of eco-efficiency.

3. The concept of eco-efficiency: Indicators and measures

The concept of eco-efficiency considers the skill in measuring the evolution of an economic activity in an environmentally sustainable manner to meet human needs and upgrade the quality of life, steadily reducing environmental impacts and the consumption rates of natural resources, based on the environmental capacities of the planet (World Business Council for Sustainable Development, 2000).
Table 1 presents key elements for improving the eco-efficiency of any economic activity. It also shows a set of principles guaranteeing that the recommended indicators and way of attaining them are justifiable in scientific terms, as well as being useful, accurate and relevant for the environment.

3.1. Eco-efficiency indicators

The World Business Council for Sustainable Development report sets out a framework that can be used by any business to measure progress toward economic and environmental sustainability. A small set of indicators, called generally applicable, has been identified as being valid for virtually all businesses. Other indicators need to be used by individual companies to fit their particular context; these are termed business specific. To determine eco-efficiency indicators, the Council proposed a triple-tiered structure: categories, aspects and indicators. The categories represent the broadest-ranging classification level for the indicators, and are associated with determining the results (products or services values) and resources involved in the activities (environmental influence). Each category has a set of aspects defined as the way in which the related data are revealed. Each aspect may have various indicators, which are its specific expressions, and will be used to build up the eco-efficiency measures.

The general applicable indicators for product/service value are quantity produced and net sales. Those relating to product/service creation environmental influence are total energy consumption, materials (raw and ancillary materials) and water consumption, greenhouse gas emissions and

<table>
<thead>
<tr>
<th>Key elements</th>
<th>(1) Reduced material intensity;</th>
<th>(2) Reduced energy intensity;</th>
<th>(3) Reduced dispersion of toxic substances;</th>
<th>(4) Enhanced capacity of recycling material;</th>
<th>(5) Maximised use of renewable resources;</th>
<th>(6) Extended product life cycles;</th>
<th>(7) Increased service intensity.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principles</td>
<td>(1) Be relevant and meaningful in terms of environmental protection, human health and/or improving the quality of life;</td>
<td>(2) Inform decision making to improve the performance of the organisation;</td>
<td>(3) Recognise the inherent diversity of business;</td>
<td>(4) Support benchmarking and monitoring over time;</td>
<td>(5) Be clearly defined, measurable, transparent and verifiable;</td>
<td>(6) Be understandable and meaningful to identified stakeholders;</td>
<td>(7) Be based on an overall evaluation of a company’s operation, products and services, especially focusing on all those areas that are of direct management control;</td>
</tr>
</tbody>
</table>

ozone depleting substance emissions. All indicators of product/service use environmental influence are considered to be business specific.

3.2. Eco-efficiency measures

The eco-efficiency measures (EM) are performance measures obtained through the ratio between product/service value indicators ($V$) and those for environmental influence caused by generation or use of the product/service (EI);

$$EM = \frac{V}{EI}$$

Eco-efficiency measures enable inclusion of other performance measures on road transport energy-efficiency programs. These new measures should consider both the economic (financial costs) and environmental (natural resources use, pollutant emissions etc) aspects of those programs. In a broader sense, service value indicators are the expression of transport capacity, such as the number of passengers or the volume of freight transported by a distance.

4. Eco-efficiency management program (EEMP)

The Eco-Efficiency Management Program (EEMP) is a suggestion for improvement of traditional energy-efficiency programs devoted to reduce fuel consumption. EEMP proposes a short-term cost/benefit analysis to improve the economic aspect of such programs and the inclusion of supplementary environmental aspects in the management of energy end use.

The core principle of EEMP is the use of eco-efficiency measures to evaluate its results, as discussed in the previous section. Nevertheless, to implement EEMP, the functional concept of the program should be taken under consideration.

4.1. Functional concept of EEMP

In practice, EEMP can be divided in two phases: planning and operational. It is also suggested two types of participants: the manager and the operators.

EEMP and its supplementary programs begins with the planning phase, selection of eco-efficiency indicators, operators’ identification, data acquisition routine, eco-efficiency measures (EM) determination and its respective targets.

The operators must act on an induced basis, keeping the program manager advised of all information required for the planning and operation of the EEMP. In addition they must implement, maintain and upgrade the supplementary programs.

4.2. EEMP supplementary programs

A set of supplementary programs, known as operational programs, is necessary in the operational phase of EEMP. Those programs are; regular inspections by the program manager, vehicles inspection programs (VIP), divided into weekly inspections (WI) and monthly inspections (MI),
vehicles maintenance programs (VMP), fuel control programs (FCP), and alternative energy programs (AEP).

The VIP, VMP and FCP are part of ordinary fleet management programs, already implemented by EEMP operators. They represent tools to maintain good operational condition of the fleet and costs control. It is frequently possible to adjust those existing programs with the EEMP demands, what makes its implementation simple, fast and cheap. The AEP looks at the opportunity to use cleaner and/or renewable fuels. The AEP must answer many relevant questions, related to the type of alternative fuel, its use extension, and its costs and economic/ecological viability.

4.3. Eco-efficiency measures evaluation and performance target definition

The study of each specific transport activity will show which eco-efficiency indicators are best adapted to represent service value. For the environmental influence indicators, a preliminary set of five indicators is suggested; total energy, renewable energy, greenhouse gas emissions, atmospheric pollutant emissions, and equivalent annual cost. The selection of these eco-efficiency indicators is aligned with the main purposes of EEMP and complies with the key-elements and principles outlined in Table 1.

Fig. 1 illustrates the functional diagram proposed for EEMP eco-efficiency measures evaluation. It is based on calculating the eco-efficiency measurements (EM) and compared to a proper target. If no improvement is needed the fleet is kept under inspection programs and fuel economy
control. Otherwise it is possible to use VMPs, FCPs, and AEPs to improve eco-efficiency measures and reach the performance targets.

Taking a fleet of NV\textsubscript{ij} vehicles, where \(i:1..n\) represents each different type of vehicle and \(j:1..m\) represents each different type of fuel; the total energy consumption (\(E\)) in a period of time can be evaluated as Eq. (2).

\[
E = \sum_{j=1}^{m} \left( \sum_{i=1}^{n} \text{NV}_{ij} \cdot \frac{1}{\text{FE}_{ij}} \cdot \text{KM}_{ij} \right) \cdot \text{CC}_{j}
\]  (2)

where \(\text{FE}_{ij}\) is the fuel economy of vehicle type \(i\) using fuel type \(j\) \([\text{km/l}]\); \(\text{KM}_{ij}\) is the total distance covered by vehicle type \(i\) using fuel type \(j\) \([\text{km}]\) and \(\text{CC}_{j}\) is the calorific content of fuel type \(j\) \([\text{GJ/l}]\).

A sub-set of total energy consumption is total renewable energy consumption (RE), determined using Eq. (2) restricted to those vehicles that use renewable fuel.

The total emission of carbon dioxide (CO\(_2\)) is evaluated using Eq. (3).

\[
\text{CO}_2 = \sum_{j=1}^{m} \left( \sum_{i=1}^{n} \text{NV}_{ij} \cdot \frac{1}{\text{FE}_{ij}} \cdot \text{KM}_{ij} \right) \cdot \text{EF}_j
\]  (3)

where \(\text{EF}_j\) is the CO\(_2\) emission factor of fuel \(j\) \([\text{gCO}_2/\text{l}]\).

The total emission of each greenhouse gas (GH\(_G_p\)), other than CO\(_2\), is:

\[
\text{GHG}_p = \sum_{j=1}^{m} \sum_{i=1}^{n} \text{NV}_{ij} \cdot \text{EF}_{ijp} \cdot \text{KM}_{ij}
\]  (4)

where \(\text{EF}_{ijp}\) is the emission factor of GH\(_G_p\) from vehicle type \(i\) using fuel type \(j\) \([\text{g/km}]\).

The total greenhouse gas (TGHG) emission, in equivalent tons of carbon dioxide (CO\(_2\)) is

\[
\text{TGHG} = \text{CO}_2 + \sum_{p=1}^{\rho} \text{GHG}_p \cdot \text{CF}_p
\]  (5)

where \(\text{CF}_p\) is the conversion factor from the GH\(_G_p\) to CO\(_2\) \([\text{gCO}_2/\text{gGHG}]\).

Considering a set of \(k:1..s\) atmospheric pollutant substances, its total emission (\(P_k\)) is evaluated using:

\[
P_k = \sum_{j=1}^{m} \sum_{i=1}^{n} \text{NV}_{ij} \cdot \text{EF}_{ijk} \cdot \text{KM}_{ij}
\]  (6)

where \(\text{EF}_{ijk}\) is the emission factor of atmospheric pollutant \(k\) from vehicle type \(i\) using fuel type \(j\) \([\text{g/km}]\).

Cost analysis should consider all the fuel-related costs, as much as for EEMP planning and operational phases and any necessary investment to introduce an alternative fuel. The net present value of the costs is obtained considering adequate discount rate and project term that are also very specific for each operation. The equivalent annual cost (EAC) is a constant annual cost that determines the same net present value considering the same discount rate and project term.

Costs to implement EEMP depend on fleet size and transport operation. The same applies to investments and costs for alternative energy sources. The fuel costs can be determined by
where \( C \) is the cost of fuel \( j \)—[$/l].

For road transport energy-efficiency programs the key in performance target definition is vehicle’s fuel economy. If it is possible to identify a improved fuel economy (IFE\(_{ij}\)) for vehicle type \( i \) using fuel type \( j \) through the implementation of EEMP over a pilot test, Eqs. (3), (4), and (7) can be use to determine improved eco-efficiency measures that can be used as performance targets.

For greenhouse gases and atmospheric pollutants, the performance target determination is not so simple, although it follows the same principle: the identification of an improved emission factor (IEF) after the appliance of EEMP measures.

Measure air pollutant emissions is much more difficult than fuel economy, since it demands hardly available expensive equipment. Even though, if less fuel is consumed, some reduction on emissions is expected and it is suggested that it be considered proportional to fuel reduction for an initial estimate. If a proper service value indicator (\( V \)) is choose, the eco-efficiency measures and performance targets are obtained as expressed in Table 2.

### 5. The EEMP potential application

The EEMP potential application was tested through a case study undertaken for the Brazilian airport authority (INFRAERO, 2001). Its 2002 business plan established a energy reduction target of 10% for the road vehicle fleet supporting aircraft ground operation within one year. Alike many other energy-efficiency programs some questions where missed: It is a reasonable fuel reduction target? What are the costs involved? What are the environmental benefits and how to enlighten them? Despite this fact, some other aspects support the case study choice:

- It offers the opportunity to model the relationship between the program manager (INFRAERO) and a large number of operators, established as 61 individual service providers, what is a common aspect on energy-efficiency programs;
- The disposition of complete one year fuel economy records of a heterogeneous fleet of 671 road vehicles—14 types of diesel propelled vehicles, 4 types of gasoline, hydrated ethanol and compressed natural gas (CNG) propelled vehicles;

### Table 2

<table>
<thead>
<tr>
<th>Eco-efficiency measure</th>
<th>Expression</th>
<th>Performance target</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency</td>
<td>( V/E )</td>
<td>( V/E' )</td>
<td>Where ( E' ) is obtained using IFE</td>
</tr>
<tr>
<td>Renewable energy efficiency</td>
<td>( V/RE )</td>
<td>( V/RE' )</td>
<td>Where ( RE' ) is obtained using IFE</td>
</tr>
<tr>
<td>Global warm efficiency</td>
<td>( V/TGHG )</td>
<td>( V/TGHG' )</td>
<td>Where TGHG' is obtained using IFE and IEF</td>
</tr>
<tr>
<td>Air pollutant efficiency</td>
<td>( V/P _k )</td>
<td>( V/P _k' )</td>
<td>where ( P _k' ) is obtained using IFE and IEF</td>
</tr>
<tr>
<td>Cost efficiency</td>
<td>( V/EAC )</td>
<td>( V/EAC' )</td>
<td>Where EAC' is obtained considering the costs to implement the EEMS and FC uses IFE</td>
</tr>
</tbody>
</table>
• Four types of fuel are already in use—diesel oil, gasoline (containing 22% anhydrous ethanol), hydrated ethanol and CNG. Two of them are renewable—anhydrous and hydrated ethanol. One of them is considered cleaner—CNG;
• It is difficult to find such a set of transport operators featuring a so heterogeneous fleet and diverse fuel use in the same place. It enables to test EEMP implementation on an extreme situation;
• It was possible to choose a service value that is non conventional for transport activity;
• The fleet undergoes 7 days a week, 24h a day of hard and unsteady operation.

Moreover, the most important results are the ways EEMP is implemented and how to use eco-efficiency measures and define performance targets to improve road transport energy-efficiency programs. Any value estimate and quantitative result are very specific of the case study and should not be considered in general.

5.1. Implementing EEMP

Within EEMP planning phase, it was clear that INFRAERO was the program manager. The operators were identified, to draw up an inventory of the vehicle fleet and obtain an understanding of their operations and the factors that affect their fuel economy.

This task required a detailed knowledge of the vehicles and their operations both inside and outside Rio de Janeiro International Airport, what was acquired after three months of research in the airport facilities and considering information obtained through interviews with participants and consulting previous year database.

As expected, all operators have some kind of periodic vehicle inspection, fuel economy control and vehicle maintenance program. It was only necessary to improve and standardise those activities to fit EEMP demands, which was done based on EEMP operational programs. It was also necessary to establish a data exchange routine among program manager and operators, which was done using intranet service.

Aircraft landing and take off (LTO) was taken in place of any other service value indicator, such as transported passengers and/or freight. This decision was based on:

• It is difficult to establish a straight relationship between transported passengers and/or freight and the roadway fleet supporting aircraft ground operations fuel consumption because nowadays a single aircraft carries both passengers and a large amount of freight and no distinction is made in ground operation assistance;
• In the case studied, the amount and the type of road vehicles assisting aircraft depends on the place where aircraft stop and not the transported matter;
• LTO is a common measure for service-providers (operators) and INFRAERO (manager), what is not the case of any other service value indicator.

To estimate monthly LTO figures the aggregate data for the twelve months in 2002 were used. The environment indicators are total energy, renewable energy, greenhouse gas emissions, atmospheric pollutants—restricted to particulate matter (PM), and equivalent annual cost.

To deter-
mine fuel economy (FE), one year of fuel economy records were analysed. These values were determined considering an experimental error of 5% over the mean value on a level of significance of 90%. The main figures are on Table 3.

A three-month pilot program was established to determine improved fuel economy for each type of vehicle within its specific operation pattern. A randomly chosen control fleet, accomplishing 60% of all vehicles, was put under EEMP operation programs routine.

The vehicles suffered weekly and monthly inspection. If necessary they were regulated and suffered light maintenance (engine and fuel system regulation). All drivers were trained on fuel efficiency conduction. Fuel storage and handling were re-evaluated and procedures were changed if necessary. Smoke emissions were measured and again the vehicles were regulated if necessary.

It was observed that all the vehicles that suffered inspection were send for any kind of regulation. That was the main reason to determine a three-month pilot program, within this period all vehicles suffered light maintenance.

It was considered a reasonable decision to count all inspections, driver’s training and light maintenance costs as EEMP costs, but only 15% of VMP’s costs include vehicle’s fuel system maintenance. Table 4 presents the costs considered for EEMP implementation.

### Table 3

<table>
<thead>
<tr>
<th>Vehicles type</th>
<th>Number of vehicles per fuel type</th>
<th>FE&lt;sup&gt;a&lt;/sup&gt;</th>
<th>IFE&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diesel oil</td>
<td>Gasoline</td>
<td>Hydrated ethanol</td>
<td>CNG&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Air conditioning truck</td>
<td>15</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Self-propelled stair</td>
<td>19</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Self-propelled mat</td>
<td>18</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Aircraft loader</td>
<td>43</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Aircraft push back tow tractor</td>
<td>31</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Water truck</td>
<td>6</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sewage truck</td>
<td>8</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Tractors</td>
<td>114</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Self-propelled energy unit</td>
<td>43</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Towed energy unit</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Fuel pumping truck</td>
<td>23</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Fuel tank truck</td>
<td>14</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Catering truck</td>
<td>52</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Minibuses</td>
<td>11</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Cargo van</td>
<td>–</td>
<td>56</td>
<td>4</td>
<td>–</td>
</tr>
<tr>
<td>Passengers van</td>
<td>–</td>
<td>93</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Pick up</td>
<td>–</td>
<td>35</td>
<td>5</td>
<td>–</td>
</tr>
<tr>
<td>Passenger cars</td>
<td>–</td>
<td>52</td>
<td>2</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>399</td>
<td>236</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: Ribeiro et al. (2002).

<sup>a</sup> The fuel economy (FE) and improved fuel economy (IFE) presented in this table fits for diesel oil and gasoline fuelled vehicles. A conversion rate was obtained for hydrated ethanol and CNG fuelled vehicles—1 km/l (gasoline)—0.74 km/l (hydrated ethanol)—1.03 km/m³ (CNG).

<sup>b</sup> Compressed natural gas (CGN) used in gasoline-CNG bi-fuel vehicles.
Over 700 fuel economy records were generated from the pilot program. At least 30 records for each vehicle type. The improved fuel economy rates showed in Table 3 were also determined considering an experimental error of 5% over the mean value on a level of significance of 90%.

To determine CO2 emissions, the factors used are on Table 5. Anhydrous and hydrated ethanol are bio-fuels obtained from sugar cane and produce none CO2 emissions when burned. No other GHG emission other than CO2 was determined, since it was not possible to measure.

The only atmospheric pollutant that was possible to be estimated was particulate matter (PM). It was done by smoke analysis over the control fleet. The average PM emission factors per fuel type are also presented on Table 5.

Fuel costs were obtained among program operators; figures presented on Table 5 are mean values. Equivalent annual costs (EAC) were obtained considering all fuel costs. After consulting program participants it was considered reasonable to use a discount rate of 18% (annual basis), what is the mean value of the discount rates practiced by each participant. The project term was the fifth year, since it is the usual renewable point for light duty vehicles.

Table 4
EEMP implementation costs

<table>
<thead>
<tr>
<th>Cost Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEMP planning costs</td>
<td>$44,000</td>
</tr>
<tr>
<td>EEMP operational costs</td>
<td></td>
</tr>
<tr>
<td>Inspections, driver training and light maintenance costs [$/year]</td>
<td>$76,265</td>
</tr>
<tr>
<td>Inspection, driver training and light maintenance costs [$/vehicle-year]</td>
<td>$113.66</td>
</tr>
<tr>
<td>Vehicle's maintenance costs [$/year]</td>
<td>$166,099</td>
</tr>
<tr>
<td>Vehicle's maintenance costs [$/vehicle-year]</td>
<td>$247.54</td>
</tr>
<tr>
<td>Total EEMP annual costs [$/year]</td>
<td>$242,365</td>
</tr>
<tr>
<td>Total EEMP annual costs [$/vehicle-year]</td>
<td>$361.20</td>
</tr>
</tbody>
</table>

Source: Ribeiro et al. (2002).
Notes: Planning costs consider 5 people working 10 months. Weekly inspection considers 5 inspectors attending 24 vehicles a day and working 7 days a week. Monthly inspection considers 2 inspectors attending 16 vehicles a day and working 30 days a month. Light maintenance considers 5 workers working full time to answer EEMP demand. All legal charges and social benefits are also included. Spare parts and components are not considered because they are part of standard maintenance costs.

Table 5
Emission factors and fuel prices

<table>
<thead>
<tr>
<th>Fuel</th>
<th>CO2 EFa</th>
<th>Unit</th>
<th>PM EF</th>
<th>PM IEF</th>
<th>Fuel priceb</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel oil</td>
<td>2.64</td>
<td>GCO2/l</td>
<td>0.81</td>
<td>0.68</td>
<td>$0.4904</td>
<td>$/l</td>
</tr>
<tr>
<td>Gasoline</td>
<td>2.23</td>
<td>GCO2/l</td>
<td>0.08</td>
<td>0.016</td>
<td>$0.6950</td>
<td>$/l</td>
</tr>
<tr>
<td>Ethanol</td>
<td>0</td>
<td>GCO2/l</td>
<td>0.02</td>
<td>0</td>
<td>$0.3821</td>
<td>$/l</td>
</tr>
<tr>
<td>CNG</td>
<td>2.17</td>
<td>GCO2/m³</td>
<td>0.001</td>
<td>0</td>
<td>$0.3693</td>
<td>$/m³</td>
</tr>
</tbody>
</table>

a Based on Ministério da Ciência e Tecnologia (2003).
5.2. Case study and discussion

Table 6 presents the case study eco-efficiency indicators and measures. These figures are expected before the EEMP implementation and represent the baseline. No EEMP costs were included in EAC determination. Once the IFE rates and EEMP costs were determined, through the three-month pilot program, it is possible to obtain the performance targets.

It is also possible to draw up additional energy use assumptions, where renewable or cleaner energy sources are favoured. For practical considerations four assumptions were made. Two of them include EEMP implementation.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Type</th>
<th>Unit/year</th>
<th>Eco-efficiency measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road fleet supporting aircraft ground operation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participants</td>
<td>INFRAERO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operators 671 vehicles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fleet Eco-efficiency indicators</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Indicator</td>
<td>Quantity</td>
<td>Eco-efficiency measures</td>
</tr>
<tr>
<td>Service value</td>
<td>Aircraft landing and take-off operation</td>
<td>89.217</td>
<td>LTO&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Environmental Influence&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Total energy (E)</td>
<td>122,973</td>
<td>GJ/year</td>
</tr>
<tr>
<td></td>
<td>Non renewable energy</td>
<td>78,872</td>
<td>Diesel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36,994</td>
<td>Gasoline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4574</td>
<td>CNG</td>
</tr>
<tr>
<td></td>
<td>Total renewable energy (RE)</td>
<td>9.383</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2533</td>
<td>GJ/year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6850&lt;sup&gt;c&lt;/sup&gt;</td>
<td>GJ/year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total greenhouse gas emissions (TGHG)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>8033</td>
<td>EqCO&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td></td>
<td>Atmospheric pollutant emissions (P)</td>
<td>4.35</td>
<td>MP</td>
</tr>
<tr>
<td></td>
<td>Equivalent annual costs (EAC)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>$1710.213</td>
<td>US dollars</td>
</tr>
</tbody>
</table>

Source: Ribeiro et al. (2002).

<sup>a</sup> Landing and Take Off, representing one complete aircraft ground operation.

<sup>b</sup> All the indicators determined following equations 3 to 7.

<sup>c</sup> Brazilian gasoline contains 22% of anhydrous ethanol.

<sup>d</sup> Only CO<sub>2</sub> emissions are considered.

<sup>e</sup> Considering a 5 year project term and discount rate of 18% annual basis.
**Assumption 1 (A1):** EEMP is not implemented and all vehicles are converted to CNG. The conversion price is $770 per vehicle and the investment on natural gas compression is $73,750, roughly 24.2% of a $312,500 compression station for 1000 vehicles per day, since there are 242 vehicles using gasoline and hydrated ethanol. (Folha do GNV, 2003);

**Assumption 2 (A2):** A1 plus EEMP implementation;

**Assumption 3 (A3):** EEMP is not implemented and all gasoline and CNG vehicles are substituted by hydrated ethanol ones. A cargo or passenger van costs $8,700 and a pickup $8,300. A passenger car costs $9,300 and it is even possible to by flexible fuel vehicles (Quatro Rodas, 2003);

**Assumption 4 (A4):** A3 plus EEMP implementation.

Assumptions 1 and 3 are additional baselines for EEMP implementation. They considered the possibility of fuel change before EEMP implementation. The main question to be answered is if it is possible to reach a better performance changing fuel and not implementing EEMP.

For each eco-efficiency measures, Figs. 2 and 3 show the results of each assumption compared to the baseline and target values. The greater its value better it is. This is found for all the eco-efficiency measures but renewable energy efficiency, which is discussed later. If no renewable energy is used, renewable energy efficiency cannot be defined. In the case study, energy efficiency target estimate reaches 86.88 LTO/100 GJ, 19.8% better then the baseline. A proportional improvement on global warm efficiency (19.7%) and 21.5% improvement on particulate matter efficiency are expected.

The energy efficiency improvement compensates the necessary investment and costs to EEMP implementation. It is possible to observe a small improvement on cost efficiency (3.9%). Cost efficiency is an important measure because it signalises the level of energy reduction that compensates additional costs and guarantee the economic return of the program. It was the energy efficiency improvement smaller than 14% and no cost efficiency improvement could be observed. In this

![Fig. 2. Energy efficiency (E), cost efficiency (EAC) and atmospheric pollutant efficiency (P) measures.](image-url)
case, it would be a mistake to follow INFRAERO’s Business Plan and set the energy reduction on 10%.

On the other hand, if the planning costs for EEMP are greater than $285,000, or its operational costs greater than $318,000 per year, no improvement on cost efficiency is expected. As it is possible to see, EEMP cost efficiency is much more sensible to annual operational costs than to planning costs.

Cost efficiency should not be considered on an isolated way, as A1 shows, the use of CNG alone is able to improve cost efficiency over 22% compared to baseline, but energy efficiency drops close to 10%. The same thing happens to global warm efficiency, a reduction of 7.5% is observed. Even considering some improvement on particulate matter efficiency, the target is not reached.

Brazilian gasoline has 22% of anhydrous ethanol, a renewable fuel, and its complete substitution for CNG do not contribute to global warm efficiency improvement. CNG also has a greater calorific content (9252 kcal/m³) than Brazilian gasoline (8980 kcal/kg) or hydrated ethanol (6650 kcal/kg) (Ministério das Minas e Energia, 2003). Even creating a slightly better fuel economy, the total energy in GJ consumed by CNG is greater than for gasoline.

If besides the use of CNG, EEMP is implemented (A2), the cost efficiency improvement is close to 17% and energy efficiency is set above the baseline but below the target. The same thing happens to global warm efficiency but the best improvement is observed for particulate matter efficiency, roughly 43% for both cases.

The use of renewable fuels in A3 and A4 is fairly the best way to improve global warm efficiency. If conjugated to EEMP implementation, it is also a good way to improve energy and particulate matter efficiencies. But because of large investments on vehicle substitution, its cost efficiency drops 32%. If fuel substitution is done the same time as fleet substitution, the real investment represents only the difference between gasoline and hydrated ethanol fuelled vehicle's price, what is insignificant on Brazilian market. In this case cost efficiency turns to be attractive (58.49 LTO/$1000). Nevertheless, the investment on fleet must exist.

The renewable energy efficiency should always be analysed along with energy and global warm efficiencies. If the renewable energy efficiency baseline is compared to A3, a reduction of its value indicates that more renewable energy is consumed for the same service value, what is a desirable situation. It leads to an improvement on global warm efficiency and a slight reduction on energy
efficiency, what is not desirable. If the renewable energy efficiency baseline is compared to A4, a reduction of its value also indicates that more renewable energy is consumed for the same service value. But in this case a desirable improvements on global warm and energy efficiencies are observed.

Comparing the baseline, each assumption and performance target, the implementation of EEMP is a way to improve eco-efficiency measurements other than cost efficiency. At the same time it is the only way to reduce diesel oil consumption in the case study.

6. Conclusions

This work presents a way to implement eco-efficiency management programming that, determines eco-efficiency measures and performance targets. In the case of performance targets, the procedure to determine them is an important contribution to road transport energy-efficiency programs. The case study enables testing of the implementation of the EEMP in an activity with a significant number of participants, with heterogeneous vehicle types, functions and fuel uses. The results indicate that EEMP is adaptable to the activities of other types of road fleets with fewer types of vehicles and more specific functions, such as urban freight, urban transit and long distance transport.

It is quite valid to consider the application of the EEMP to situations where the program managers and operators belong to the same enterprise—such as a shipping company—and where the planning department would be the program manager and the operations department would function as the operator. A situation such as this could make the implementation of the EEMP even easier. Consequently, the flexibility of the program is quite clear for its application to other types of fleets, as well as for rail and water-borne shipping systems.

References


