Development and use of a model for the investigation of energy and emission aspects on the Athens-Thessaloniki rail intermodal freight transport

Eleni Tournaki* and Athanasios Ballis

National Technical University of Athens,
5 Iroon Polytechniou St.,
Zografou Campus, 15773, Athens
Email: eltournaki@mail.ntua.gr
Email: abal@central.ntua.gr
*Corresponding author

Abstract: Environmental protection is an issue that rises in importance in the agenda of the priorities in transportation sector. Railways are perceived to contribute positively towards such a direction. The current work focuses on the actual parameters that affect energy and emissions in rail freight transport. These parameters were investigated using a model. Input variables include technical and operational characteristics of the railway track, the rolling stock and the loading units as well as the restrictions of the wagons’ loading process, which prevent railways to operate at full capacity. The model was validated on the main Greek railway corridor connecting Athens to Thessaloniki. The analysis revealed and quantified the impacts affecting energy and emissions: train load factor, train speed, gradient profile of railway track, rolling stock types, payload of transported loading units, rules of efficient wagon loading, fuel type and emission factor for electricity generation in the specific country. Comparisons with pure road transport and sensitivity analysis were also carried out on the Athens-Thessaloniki case study.

Keywords: rail transport; environmentally friendly modes; energy; pollutants; carbon footprint.


Biographical notes: Eleni Tournaki is a Civil Transport Engineer at National Technical University of Athens (NTUA) from which she graduated in May 2014. During the last years of her studies, she was occupied as an intern at companies of the transport and logistics sector (TRAINOSE SA, Flextronics Logistics Poland). She continued her post-graduate studies in the field of engineering and economic systems. Recently, she has been working as a researcher in the Department of Transportation Planning and Engineering at NTUA, taking part in research programs focusing on the freight transport field.

Athanasios Ballis is an Associate Professor in the Department of Transportation Planning and Engineering at National Technical University of Athens. He teaches in the fields of transportation planning, intermodal transport and railways technique. His areas of expertise include maritime and rail terminal design, intermodal transport, logistics and airport planning. He has an experience of more than 30 years in European transportation research projects (among them PACT, SIMET, IMPULSE, IQ, ITIP, TENNASSES, EUNET,
FMAN, EDIP, ETIS, MEDA, CREAM, ETISplus, APC, ADRIATICmos, MEDNET, MOVE, SPIDER Plus, GIFT, REBIS) as well as in national projects concerning intermodal transport and logistics. He has more than 120 publications in scientific journals and conference proceedings.

This paper is a revised and expanded version of a paper entitled ‘Development and use of a simulation model for the investigation of energy and emission aspects in rail intermodal freight transport’ presented at the 4th International Symposium and 26th National Conference on Operational Research, Chania, 4–6 June 2015.

1 Introduction

Transport is responsible for around a third of atmospheric pollutants with road transport having the biggest share (European Commission, 2012). For this reason, the European policy towards the environment includes, among others, significant initiatives for the promotion of environmentally friendly transport modes. For rail transport, this reflects the challenge to increase its share both in passengers and freight in relation to road transport.

Railways are widely accepted to be environmentally friendly. However, this is not valid in all cases: even with a rough estimation it is evident that a diesel engine of 4,500 HP and a mass of 120 t, that hauls only five freight wagons, with a payload of 25 t each, consumes more energy than 5 trucks, carrying the same load. On the other hand, an electrically driven, heavy loaded train running on metal tracks has much lower rolling and aerodynamic resistance than an equivalent fleet of trucks. Identifying the break-even load factor of a train that justifies rail transport as advantageous in respect to energy consumption and environmental impacts (greenhouse emissions) requires a systematic approach that takes into consideration various parameters.

Carbon footprint is a basic indicator for the measurement of the quantity of greenhouse emissions produced. It refers to the total quantity of greenhouse emissions produced in the atmosphere annually by a person, family, building, organisation, activity or company. It includes the greenhouse emissions from the consumption of fuel directly for the heating of a building, vehicle movement, etc as well as the emissions for the production of goods or services that a person, family, building or organisation uses. The emissions from electric power plants, industries and sanitary landfills are also included (US Environmental Protection Agency, 2014).

In the case of transport, the ‘carbon footprint’ may refer either to tank-to-wheel (TTW) or well-to-wheel (WTW) emissions. TTW emissions refer to those emissions produced by the operation of vehicles while WTW emissions refer to the total emissions produced, including those produced during the extraction, processing, transfer and distribution of fuels.

The scope of this work is to describe the development of a model which calculates the energy consumption and the corresponding carbon footprint of intermodal freight transport based on train friction theory, taking into account journey and train characteristics (speed, technical characteristics of locomotives, rolling stock and loading units, payload of transported goods), rail network characteristics (gradient profile of rail track, electrification) as well as rules/practices of wagons loading (wagons loading schema). The model is validated and applied to a specific case study.
(Athens-Thessaloniki route, which is the main Greek railway corridor) in order to identify the parameters that affect the pollutants emitted by intermodal rail transport and the technical and operational conditions that must be met in order for railway transport to be more advantageous than road transport in terms of energy consumption and pollutants emitted (at least for the route under investigation). In the remainder of this paper, a brief literature review (Section 2), the description of the model structure (Section 3) and the results of the case study conducted (Section 4) are presented. The conclusions are drawn in the last section (Section 5).

2 Literature review

Several different models for calculating the energy consumption of trains exist in the literature. A number of these works concern models that calculate energy either based on the average speed and distance between successive stops (simplified model of project MEET) or taking into account the number of stops, the route distance, the difference in altitude at the beginning and at the end of the route and maximum and average speed of the train (analytical model of project MEET) (Hickman et al., 1999). A different approach is based on the calculation of energy consumption per kilometer arising as a function only of the gross mass of the train (IFEU & SGKV model) (Helms et al., 2003), while, in the development of computational tool EcotransIT World, the only independent variable was again only the mass of the train (IFEU Heidelberg et al., 2010). In Section 3, a comparison between the model described in the current paper against the four aforementioned models is carried out.

Estimations of traffic flows and the corresponding pollutants were reached by a number of works, e.g., Cristea et al. (2013) where data between different origins-destinations were used, Bauer et al. (2010) which proposed solutions that minimise emissions in transport services, etc. Furthermore, certain organisations have published guidelines for the calculation of emissions of freight transport, such as the instructions of CEFIC (2011) for the assessment, management and evaluation-promotion of good practices to reduce emissions from transport services, as well as the model developed by Martinez et al. (2014) to estimate the transported volume and the corresponding emissions by international freight flows, bridging the gap between the measurement and modelling of environmental impacts in the transport sector.

3 Modelling energy consumption and emissions in rail transport

The calculation of fuel consumption and emissions produced in rail freight transport is a multifaceted problem. The main parameters that affect it and are taken into account for the calculation of energy consumption are: the traction system, the total mass of the train, the train speed, the technical characteristics of the rail track, the technical characteristics of the rolling stock, etc.

The methodological approach presented in the current work, calculates, at first, the energy consumption and next estimates the ‘carbon footprint’ of a rail intermodal freight transport and its ‘equivalent’ road transport. This is achieved by entering the total payload of the examined transport and its distribution to light, medium-light and heavy
commodities as well as the characteristics of the containers that will be used for the transport, in order to calculate their exact number. In parallel, taking into account (data input) the characteristics of the road transport [distance, percentage of distance travelled within urban network, longitudinal gradient characteristics (hilly/level ground)] the associated energy consumption and emissions of the road transport are calculated, according to the method described in CLECAT and DSLV guidelines (Schmied and Knörr, 2012). In respect to the corresponding rail transport, the containers are loaded on freight wagons by use of a loading algorithm which takes into account the restrictions imposed by the Loading Regulation of OSE (Greek Railway Company) as well as the characteristics of wagons and the rail network (Ballis et al., 2014). Then, the required number of locomotives is calculated based on their types and characteristics and considering other parameters of the specific route and journey. After finalising the synthesis of the train, its total mass and finally the relevant energy consumption and emissions are calculated (Tournaki, 2014).

The model developed for the calculation of the energy consumption and the pollutants of rail transport takes into account the resistances of the locomotives, the rolling stock and the railway track, that the train must overcome while moving. The mathematical formulation used is composed by equations obtained by various sources (Altmann et al., 1975; Karlaftis and Lyberis, 2009; Lyberis, 2010; IFEU Heidelberg et al., 2010). The emission factors derived from the European Standard EN16258 (European Committee for Standardization, 2012). As mentioned before, the method described in CLECAT and DSLV guidelines was used to calculate the energy and the carbon footprint of road transport in order to compare the latter with the corresponding carbon footprint of intermodal rail transport. The basic equation of the model that transforms the overall resistances of a moving train to energy consumption is the following (Altmann et al., 1975):

\[
\alpha \left( \frac{W_h}{t \cdot km} \right) = 2.78 * \Sigma w
\]

where
\[
\alpha \quad \text{energy consumption}
\]
\[
\Sigma w \quad \text{overall resistances}
\]
\[
2.78 \quad \text{conversion factor} \left( \frac{2.78 = \left( \frac{daN}{t} \right) \cdot \frac{1 W \cdot s}{N \cdot m} \cdot \frac{1,000 m}{1 km} \cdot \frac{1 h}{3,600 s} \cdot \frac{10 N}{1 daN} }{t} \right)
\]

The resistances, taken into account, are:

a  the curve resistance
b  the rolling resistance
c  the slope resistance.

At first, the rolling resistance of locomotives and the rolling resistance of rolling stock are calculated using the following equations (Karlaftis and Lyberis, 2009; Lyberis, 2010):

\[
W_{LOC} = 5 \cdot G_w + 4 \cdot \left( \left( V' + 15 \right) \right)^2
\]

\[
V' = \frac{v}{10}
\]
where

\[ W_{\text{LOC}} \] rolling resistance of locomotive [N]

\[ G_W \] load on the wheels [kN]

\[ V \] speed of train [km/h].

\[ W_{\text{ROL,FR}} = c_0 + (0.007 + m) \left( \frac{V}{10} \right)^2 \]

where

\[ W_{\text{ROL,FR}} \] rolling resistance of freight wagons [%]

\[ c_0 = 1.4/2.0 \] coefficient for sliding bearings/rolling bearings (respectively) of the axles

\[ V \] speed of train [km/h]

\[ m = 0.05/0.025 \] for covered wagons/flat wagons (respectively).

Then, the rolling resistance of the entire train is calculated:

\[ W_{\text{ROL,T}} = \frac{n * W_{\text{LOC}} + W_{\text{ROL,FR}} * G_{\text{HM}}}{G_T} \]

where

\[ W_{\text{ROL,T}} \] rolling resistance of the entire train

\[ n \] number of locomotives

\[ W_{\text{LOC}} \] rolling resistance of locomotive [N]

\[ W_{\text{ROL,FR}} \] rolling resistance of freight wagons [%]

\[ G_{\text{HM}} \] mass of hauled wagons [kN]

\[ G_T \] total mass of train [kN].

The slope resistance arises from the profile of the gradient of the examined route. The curve resistance was assumed to be 1.5%, which is the average value of the curve resistance of all the segments of the route. In the descending segments of the route, where the slope is higher than 4%, the energy consumption is considered to be null (as the vector of the gravity in the direction of train movement overcomes the sum of the curve resistance and rolling resistance). For the descending segments, where the slope is between –4% and 0%, the energy consumption depends only on the rolling resistance (as the curve resistance is assumed to be balanced by the above vector of gravity).

The value of the total consumption of diesel traction is calculated based on the Ecotransit method, converting the associated Wh to lt of biodiesel, according to its energy content (35.7 MJ/lt) provided in the European standard EN16258 (European Committee for Standardization, 2012). Then, the consumption for both traction systems is converted to kg CO2e, using, for
1 diesel traction, the emission factors proposed by the European standard EN 16258 for the fuel biodiesel 5% which is currently being used by OSE (WTT: 3.17kg CO₂e/lt, TTW: 2.54 kgCO₂e/lt) (European Committee for Standardization, 2012)

2 electric traction, the emission factors for the generation of 1kWh of electricity that is consumed by train, proposed by EcotransIT World (IFEU Heidelberg et al., 2010).

Model validation was performed on the 277 km segment of Domokos-Athens (where diesel traction is used). The fuel consumption figures were provided by the Greek Railways Operator TRAINOSE SA. Figure 1 depicts the validation of the proposed analytical model against the actual fuel consumption of the diesel-driven trains running on the 277 km route of Domokos – Athens. In Figure 1, the fuel consumption calculated by four other models (Ecotransit World, IFEU & SGKV, MEET analytical, MEET simplified model) is presented. The outcome indicates that the calculations of the proposed analytical model and of the IFEU & SGKV model are closer to the actual fuel consumption figures (for the rail route investigated).

**Figure 1** Validation of the proposed analytical model (as well as of the Ecotransit World, IFEU & SGKV, MEET analytical & MEET simplified model) with actual fuel consumption of the diesel-driven trains running on the 277 km route of Domokos – Athens (see online version for colours)

### 4 Results of case study

The proposed methodology for rail energy consumption was applied to Athens – Thessaloniki line, the main Greek railway corridor. The route, having a total length of 510 km, is divided into two segments:
Development and use of a model

141

a from Athens to Domokos, 277 km where trains use diesel traction

b from Domokos to Thessaloniki, 233 km where trains use electric traction

(see Figure 2).

Figure 2 Greek railway network (see online version for colours)

Source: Background map: Wikipedia, Domokos station added by the authors

The axle load is 20 t/axle and the maximum gradient is 22‰ on the segment Athens to Domokos and 14‰ in the segment Domokos-Thessaloniki (OSE SA, 2014).

In the various scenarios created below, the environmental impact of rail intermodal transport for different values of payload of goods was investigated.

It is noted that the methodology examines only the total WTW emissions as the total TTW emissions of the rail transport on the examined route are clearly fewer than the total TTW emissions of the corresponding equivalent road transport in all cases. This is because in a large part of the rail route train runs using electric traction (for which the emission factor of TTW emissions is 0 kg CO₂e/kWh).

In the investigation, three types of wagons were examined. The freight wagon Rgss has a length of 60 ft and is the main type of the wagon fleet of OSE. It is a 4-axle flat wagon suitable for containers transport having a tare weight of 23.5 t, capable of carrying a payload of up to 66.5 t. In the route of Athens-Thessaloniki, though, the maximum payload is 56.5 t due to the limit set by the maximum permissible axle load in this segment (20 t/axle). Lgns wagon is biaxial, 45-foot long with a tare weight of 11.5 t and a
maximum payload of 28.5t on the examined route. Finally, Sgnss wagon has 4 axles, is 60 ft long, having a tare weight of 20t and maximum payload 60t.

For the rail intermodal transport the following assumptions were made:

- The average train speed varies from 40 to 80 km/h. In most scenarios, the average speed was set to 60 km/h.
- The distribution of loads in light, medium-light and heavy goods was made according to some shares which have arisen from a European Research on the railway container traffic (Carrillo Zanuy et al., 2011), resulting in three classes of cargo containing:
  a. mix of light, medium-light, heavy and very heavy goods (at percentages of 43%, 30%, 19% and 8% respectively)
  b. only light goods
  c. only heavy goods (see Figure 3).
- The road segment of the intermodal transport has a total length of 30 km and takes place 100% in urban network at ground level, since trucks are considered to move exclusively within cities.

**Figure 3** Classes of cargo used in the different scenarios of the investigation (see online version for colours)
In order to investigate the influence of the emission factor for the generation of electricity and the profile of gradient of the rail track, an analysis was carried out on the examined route using four scenarios:

- **Scenario #1** concerns an intermodal transport where the train runs having an average velocity of 60 km/h, consisting of Rgss wagons, carrying light, medium-light and heavy goods with a payload of up to 500 t. The emission factor for electricity generation in Greece (0.98 kg CO₂e/kWh) is used. Moreover, the existing gradient profile of the rail route was used, obtaining the corresponding required data by OSE.

- **Scenario #2**, on the rail segment, a train with similar characteristics to the previous scenario was used. As in scenario #1, the emission factor for electricity generation was the one of Greece (0.98 kg CO₂e/kWh). However, a favourable gradient profile was adopted [considering a maximum slope of 14‰, which is the maximum allowable slope according to the new ELOT (2009) regulation].

- **Scenario #3**, the train has the same characteristics as above but the emission factor for electricity generation is the one of Germany (0.527 kg CO₂e/kWh) and gradient profile is considered to be that of the existing route. The selection of this emission factor for electricity generation was decided, in order to investigate the case where Greece replaces lignite power plants with renewable energy sources, leading the emission factor in the levels of countries such as Germany. The reduction of pollutants in such a case may reach 12% (Figure 4).

- **Scenario #4**, the emission factor for the electricity generation used was the same as the one in scenario # 3, while a favourable gradient profile with a maximum slope of 14‰ was applied, to investigate, also, the case where, in the future, the rail alignment will also, be improved. Such improvement can lead to further reduction of pollutants (additional reduction of 12%) (Figure 4).

**Figure 4** Impact of technical characteristics of rail track and of emission factor for electricity generation on WTW emissions (see online version for colours)
As far as the comparison with the equivalent road transport is concerned [510 km on hilly ground, 10% of which in urban traffic conditions, calculated based on CLECAT and DSLV (see Section 3)], road transport appears to produce fewer pollutants than the intermodal transport on the examined route, according to the current Greek conditions (scenario #1, Figure 4). This may seem unorthodox since the common perception that prevails is that rail transport, and by extension intermodal rail transport, is a more eco-friendly option than the corresponding pure road transport. However, this is not valid for all countries. In countries such as Germany, Switzerland, etc., where a significant part of the electricity consumed by trains is generated by renewable energy sources and other ecologically friendly ways, WTW pollutants produced by the rail leg of intermodal transport is clearly fewer, resulting in fewer total pollutants of intermodal transport in relation to purely road transport. In contrast, in countries such as Greece, Poland, etc., where a large proportion of electricity generated comes from burning coal and other primary energy sources whose combustion produces a large amount of pollutants, it is reasonable for intermodal transport not to be environmentally advantageous over pure road transport. Moreover, an important role on the increased emissions of pollutants of the examined route plays the quite steep gradient profile of the rail route, especially in the first section of the route, from Athens to Domokos. If any improvement on the technical characteristics of rail track or and the emission factor for electricity generation is applied, (scenarios #2, #3, #4, Figure 4), equivalent road transport becomes less environmentally friendly than intermodal transport, above a break-even point of payload of transported goods.

It is noted that the sudden change of the slope of the lines of the intermodal scenarios in the diagram is due to the fact that at these points an additional locomotive is required to haul the corresponding payload of goods, resulting in a steep increase in the total WTW emission of pollutants. This observation applies to all diagrams of the current work.

Figure 5 depicts the comparison between intermodal and the equivalent road transport for different classes of cargo of the examined case study, as discussed earlier in this section (see Figure 3). In case of heavy goods [scenario #5, Figure 5(a)], intermodal transport produces fewer pollutants than road when the payload is more than 400 t, even under the rather unfavourable Greek current conditions. In contrast, in case of light goods [scenario #6, Figure 5(b)], road transport is superior to intermodal in terms of environmental impacts regardless the value of the transported payload. This result agrees with the results of similar works that exist in European literature (see IFEU & SGKV, 2002). The result is quite reasonable as in this case (light goods), the total tare weight (tare weight of both the containers and the wagons) per net ton of goods that is transported, is much more than in the other two classes of cargo. From the diagrams, it is, also, evident that in the case of light goods the maximum payload of the goods that can be transported is about four times less than that of the heavy and very heavy goods. This occurs due to the restrictions of maximum load and maximum length of train. In the case of light goods these restrictions are satisfied for significantly lower payload of goods (for transporting less total weight, a very large number of wagons is required).
Furthermore, the investigation also pointed out the significant influence of the rolling stock used in the synthesis of the train to the total WTW pollutants produced. Figure 6 shows that if the train has an optimised synthesis of rolling stock, intermodal rail
transport can be more eco-friendly than road, even in the most unfavourable case of light goods for the Athens-Thessaloniki route [see Figure 6(b)]. The characteristics of the wagons can be found earlier in this section.

**Figure 6** Impact of optimised synthesis of rolling stock on WTW emissions, (a) intermodal scenario with *optimised rolling stock* versus road transport: mixed goods (b) intermodal scenario with *optimised rolling stock* versus road transport: light goods (see online version for colours)
Finally, a ‘Best-Case Scenario’ was created (scenario #9) (see Figure 7). More specifically, as far as this scenario is concerned, the following assumptions were made:

a  the emission factor for electricity generation is equal to the emission factor of Germany
b  the gradient profile of the route has a maximum value of 14‰
c  throughout the route (510 km) the train runs using electric traction having an average speed of 60 km/h
d  the train has an optimised synthesis of rolling stock (Sgnss and Lgns wagons with less tare weight).

The results show that, for the examined route, road transport emits significantly more pollutants than the corresponding rail intermodal transport, given all the above mentioned conditions.

**Figure 7** Comparison of pollutants emitted by ‘best-case’ intermodal rail scenario with pollutants emitted by the equivalent pure road transport (see online version for colours)

Many other analyses were performed for the identification of the relationships among all parameters involved. Table 1 shows the sensitivity analysis of the various parameters affecting the total WTW pollutants of rail transport for the specific case study presented above. A typical train of gross hauled mass 1,000 t, and payload of transported goods 400t was considered as reference scenario under scenario #1 assumptions. Under such conditions, the pollutants emitted per ton of payload calculated for the reference values were 39.7 kg CO$_2$e/t.
Table 1  
Sensitivity analysis of the total WTW emissions of intermodal transport

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reference values (scenario #1)</th>
<th>Marginal values used in the investigation</th>
<th>Difference (%) between marginal and reference values (emitted pollutants per tonne of payload)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Payload of transported goods</td>
<td>400 t</td>
<td>100 t</td>
<td>+28.1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500 t</td>
<td>–3.6%</td>
</tr>
<tr>
<td>#2 Categories of goods</td>
<td>Mix of light, medium-weight and heavy goods (average load: 7.5 t/TEU)</td>
<td>Light goods (4 t/TEU)</td>
<td>+58.1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heavy goods (23 t/TEU)</td>
<td>–36.3%</td>
</tr>
<tr>
<td>#3 Rolling stock (loading length, mass of wagon)</td>
<td>Rgss (60', 23.5 t)</td>
<td>Synthesis including Lgns κ Sgns wagons (45', 11.5 t and 60', 20 t respectively)</td>
<td>–21.6%</td>
</tr>
<tr>
<td>#4 Mix for electricity generation</td>
<td>Emission factor of Greece</td>
<td>Emission factor of Germany</td>
<td>–10.6%</td>
</tr>
<tr>
<td>#5 Average speed of train</td>
<td>60 km/h</td>
<td>40 km/h</td>
<td>–3.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80 km/h</td>
<td>+5.2%</td>
</tr>
<tr>
<td>#6 Traction system*</td>
<td>277 km diesel traction, 233 km electric traction</td>
<td>510 km diesel traction*</td>
<td>–1.8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>510 km electric traction *</td>
<td>+3.7%</td>
</tr>
<tr>
<td>#7 Gradient profile</td>
<td>Existing gradient profile</td>
<td>Assuming gradient 0% on the entire route</td>
<td>–47.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assuming gradient 14% on the segments with gradient steeper than 14% (length: 113 km)</td>
<td>–13.9%</td>
</tr>
</tbody>
</table>

Note: * Athens – Domokos (277 km): 2 locomotives, Domokos-Thessaloniki (233 km): 1 locomotive.

5 Conclusions

The issue of air pollution and the estimation of the carbon footprint produced by transport sector concerns significantly the scientific community in recent years. Freight transport by environmentally friendly means such as railways, ships, river barges, etc., have a very positive impact on efforts to reduce the emission of pollutants. Similar effects are achieved using intermodal transport, where the major leg of the journey is carried out by rail or IWW, provided that certain conditions are met.
The current work presents the structure of an analytical model for the estimation of train energy consumption and pollutants emitted. The model is based on equations of train friction theory calculating the resistances that the train has to overcome while moving. Output variables include the required number of locomotives as well as the energy consumption and pollutants emitted for different types of transported loading units and wagons and different technical characteristics of rail track. Moreover, it takes into account the restrictions imposed by the wagons’ loading regulation, which prevent railways from operating at full capacity.

The analysis conducted on the Athens-Thessaloniki line pointed out and quantified the contribution of the parameters that are involved and determine the required energy and pollutant emissions: the train and timetable characteristics (engine type, velocity), the gradient profile and the electrification of the rail track, the payload and the class of the transported goods, the rolling stock types and their loading schema and the sources used for the generation of electricity in each country. According to the analysis performed, the following conclusions were drawn: on the Athens-Thessaloniki route that is characterised by a very mountainous landscape, railway transportation is superior to road transportation, in terms of energy consumed and pollutants emitted, only when demanding conditions are met. Such a condition is the transport of heavy and very heavy goods (23–30 t/TEU), having a payload of more than 400 t. Appropriate matching of cargo classes with modern 2-axles and 4-axles wagons, having less tare weight, can radically improve the energy and environmental performance of railways as, in that way, the rail intermodal transport is more advantageous than road even in the cases of mixed and light goods (14 and 6 t/TEU, respectively). The emission factor for electricity generation plays a significant role on the amount of the emitted pollutants of intermodal transport, in the case of electrified rail tracks. If, in the future, Greece replaces lignite power plants with renewable energy sources (leading the emission factor in the levels of countries such as Germany), a reduction of pollutants of 12% may be reached. Likewise, the alignment of the route (gradient profile) has, also, a great effect on the emissions. If the existing maximum slope (22‰) of the Athens-Thessaloniki route is reduced to 14‰, which is the maximum allowable slope according to the new regulation, due to improvements on the rail alignment, the carbon footprint can be reduced at a percentage of 12%. Nevertheless, it must be noted that the above conclusions concern the specific Athens-Thessaloniki case study. Therefore, additional research is required in order to fine-tune and generalise the findings to other case studies.

References


