**Title**

# The Environmental Impacts of Logistics Systems and Options for Mitigation



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# 1. Transportation Sustainability and Green Logistics

In recent decades the environmental effects of transportation has become a topic of increasing importance around the world. As a result studies have been conducted to increase our understanding of pollutant emissions along with their consequences, and to develop schemes for impact reduction. Some researchers have also made efforts to define the long-term direction for future transportation and environmental research from a broader perspective. These analyses provide a general framework for the concept of sustainability, defining the purpose of studying transportation and the environment, which encompasses logistics systems and their impacts. In addition, research has been conducted for the purpose of including sustainability in a general framework to guide future logistics planning. As a result industry has begun to respond and make adaptations to the growing need for sustainable activities.

## 1.1 Considering Sustainability

The most widely accepted definition for sustainable development was given by the World Commission on Environment and Development in 1987, and subsequently endorsed by the United Nations at the Earth Summit in 1992[1]:

> "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Accordingly, consideration for the long-term effects of transportation activities should strongly influence policy decisions. A similar objective regarding the purpose of future research was developed by the U.K. Roundtable on Sustainable Development.[2] In addition to time scale other important aspects were also addressed:

> "to answer, as far as possible how society intends to provide the means to meet economic, environmental and social needs efficiently and equitably, while minimizing avoidable or unnecessary adverse impacts and their associated costs over relevant space and time scales."

Many transportation agencies have formulated their own definitions of sustainability, with consideration for these underlying concepts. Jeon and Amekudzi describe the sustainability strategies of various state DOTs in the United States and highlight the similarities between them.[3] Three recurring considerations are found to be especially important:

1. economic development
2. environmental preservation
3. social development

[1] [69] World Commission on Environment and Development (1987)
[2] [66] UK Roundtable on Sustainable Development (1996)
[3] [26] Jeon and Amekudzi (2005)

In the case of logistics systems, economic development can be thought of as relating to the profits and in turn the benefits to the employees of logistics companies and the indirect effects on the economy. Second, environmental preservation considers ecological impacts which can range from effects on local wildlife to those of global warming depending on analysis boundaries. Finally, social development accounts for the effects of logistics activities on human society, including the detrimental impact that pollution can have on the public. Most all studies pertaining to logistics and the environment have long-term implications based on one or more of these three considerations.

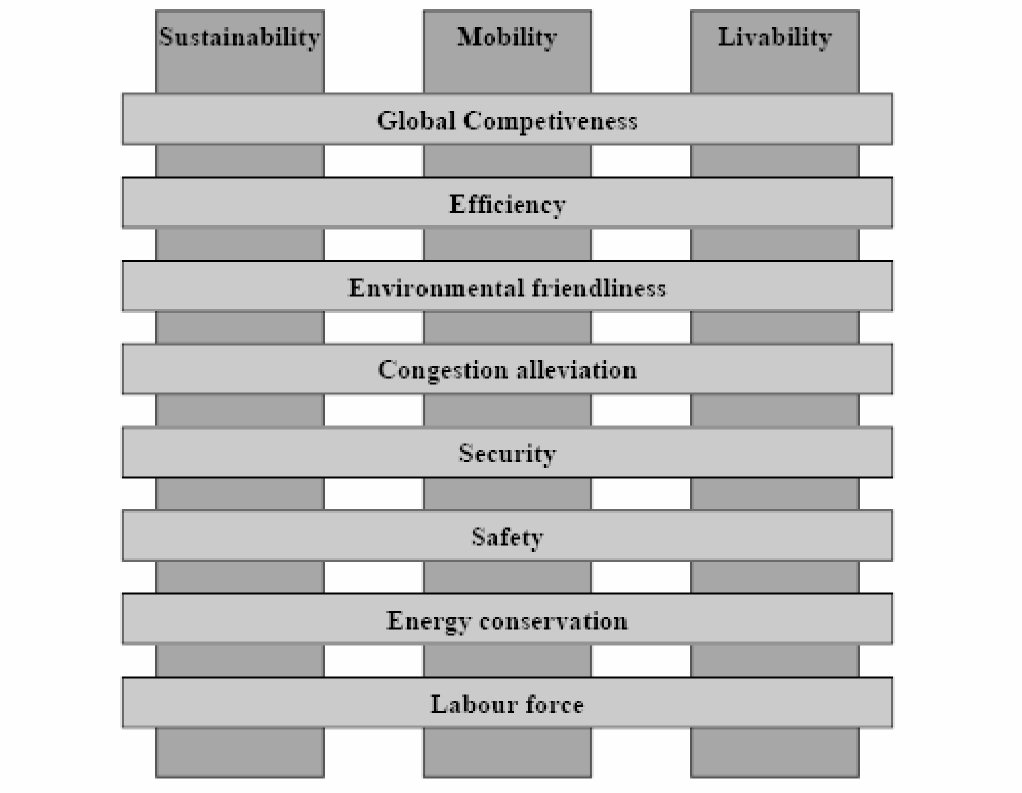
### 1.2. Considering Green Logistics with Industry Perspectives

In the past, planning and research related to freight logistics systems has primarily been focused towards the objective of increasing the efficiency of industry activities with respect to timing and profits. However, within the last 15 years growing concern over environmental impacts has spawned the concept of Green Logistics as a stimulus for developing methods which can reduce the environmental impacts of freight transportation. As a result researchers and industry have begun assessing mitigation options for planning freight transportation with consideration for environmental externalities. For the purposes of this document and to provide a general definition, Green Logistics can be thought of as an approach for planning freight logistics systems that incorporates sustainability goals with a primary focus on the reduction of environmental externalities. In accordance with this description, various studies provide some background on the current state of Green Logistics practices.

Taniguchi et al. provide a useful presentation of the objectives of Green Logistics.[4] According to their paper the three guiding pillars for the future development of green city logistics are sustainability, mobility and accessibility. These in turn support more specific goals such as environmental friendliness and energy conservation. Figure 1 illustrates their ideas. Although their intention is to describe goals for city logistics it would seem reasonable to extend these objectives to most all logistics systems. In this case the relative importance of the goals might shift, for instance congestion may not be a significant concern in many rural areas; nevertheless the framework is still applicable.

[4] [52] Taniguchi, Thompson and Yamada (2004)

**Figure 1 – Framework for the goals of city logistics.**
Source: Figure 1 in [52] Taniguchi, Thompson and Yamada (2004)




Although governments and the general public influence corporate policy, logistics companies make the final decisions which directly affect pollutant releases within their market context. Accordingly, when developing Green Logistics solutions for reducing environmental externalities, the industry perspective must be considered. Unfortunately, the goals of logistics providers often conflict with the aims of Green Logistics. Rodrigue et al. discuss these conflicts, labeling them as the "paradoxes of Green Logistics", as shown in Table 1.[5]

[5] [45] Rodrigue, Slack and Comtois (2001)

**Table 1 – Paradoxes of Green Logistics**
Source: Table 2 in [45] Rodrigue, Slack and Comtois (2001)

| Dimension | Outcome | Paradox |
|---|---|---|
| Costs | Reduction of costs through improvement in packaging and reduction of wastes. Benefits are derived by the distributors. | Environmental costs are often externalized. |
| Time / Flexibility | Integrated supply chains. JIT and DTD provide flexible and efficient physical distribution systems. | Extended production, distribution and retailing structures consuming more space, more energy and producing more emissions (CO2, particulates, NOx, etc.). |
| Network | Increasing system-wide efficiency of the distribution system through network changes (Hub-and-spoke structure). | Concentration of environmental impacts next to major hubs and along corridors. Pressure on local communities. |
| Reliability | Reliable and on-time distribution of freight and passengers. | Modes used, trucking and air transportation, are the least environmentally efficient. |
| Warehousing | Reducing the needs for private warehousing facilities. | Inventory shifted in part to public roads (or in containers), contributing to congestion and space consumption. |
| E-commerce | Increased business opportunities and diversification of the supply chains. | Changes in physical distribution systems towards higher levels of energy consumption. |

Murphy and Poist have published multiple papers on the state corporate environmental management and Green Logistics. Table 2 presents their findings based on a survey given to several company managers. The data indicate the relative importance of various policy options along with the percentage of respondent companies implementing them.[6] The table does not provide a particularly comprehensive summary of potential Green Logistics schemes, but does give insight into the industry perspective regarding attitudes and currently accepted options. Since companies aim at maximizing profits, consideration of these and other options are likely to only occur as a result of external pressure or the possibility of gaining a competitive advantage, and not purely for the goal of reducing environmental impacts. Pressure might be brought about in the form of government policies, litigation threats, or public perception. Subsequently the options which cause the greatest reduction in environmental effects are often overlooked in favor of those which are most profitable. Corporations could conceivably act out of goodwill and often may appear to do so in order to generate a positive public image; however in general to assume such motives is overly optimistic. As a result the analysis of options, which will help guide companies towards more environmentally friendly practices, is a necessity in order to meet future sustainability goals.

[6] [39] Murphy and Poist (2000)

**Table 2 – Survey results indicating the fraction of companies utilizing different policy options.**
Source: Murphy and Poist (2000)

| Strategy | Percentage of respondents: Currently use | Plan to use | No plans to use |
|---|---|---|---|
| Recycle materials whenever possible | 82.8 | 10.2 | 7.0 |
| Reduce consumption whenever possible | 81.2 | 11.3 | 7.5 |
| Reuse materials whenever possible | 73.8 | 12.8 | 13.4 |
| Conduct environmental audits | 58.8 | 18.2 | 23.0 |
| Publicize environmental efforts/accomplishments | 52.4 | 21.4 | 26.2 |
| Increase education and training of company personnel | 52.1 | 36.7 | 11.2 |
| Redesign logistical system components for greater environmental efficiency | 46.5 | 37.4 | 16.0 |
| Promote industry cooperative efforts | 45.9 | 23.8 | 30.3 |
| Use outside or third parties to manage environmental issues | 29.5 | 11.5 | 59.0 |
| Reject suppliers who lack environmental concerns | 27.0 | 30.3 | 42.7 |
| Hire/promote environmentally conscious personnel | 22.8 | 22.2 | 55.0 |
| Encourage greater governmental involvement/regulation | 16.5 | 11.2 | 72.3 |

Murphy and Poist have published results of a comparison between the environmental policies of companies from the U.S. vs. Canadian and Western European countries. Their study indicates that attitudes towards Green Logistics are much more accommodating in the "non-US" countries, showing that companies respond to pressures from external forces being either social or governmental.[7] Furthermore such results reveal that the application context must be considered prior to determining appropriate mitigation options. Subsequent sections will provide a presentation of the impacts of logistics systems to describe the characteristics of the contexts which currently exist, followed by a discussion of potential Green Logistics solutions.

[7] [40] Murphy and Poist (2003)

## 2. Externalities

Freight logistics systems are commonly thought to be an indispensable component of modern societies. Accordingly, they are not only necessary in today's world, but can also provide many non-essential benefits to citizenry. A list by Browne and Allen displays some of the important direct impacts that freight movement has in the modern world:[1]

> "-the total cost of freight transport and logistics is significant and has a direct bearing on the efficiency of the economy
> -the effect of freight transport and logistics costs on the cost of commodities consumed in the region
> -it is fundamental to sustaining our existing lifestyle
> -plays an important role in servicing and retaining industrial and trading activities which are essential wealth generating activities
> -the contribution that an efficient freight sector makes to the competitiveness of industry in the region concerned"

However, as with most mechanized transportation modes, freight logistics systems also generate negative externalities. The concept of externalities allows for the characterization of the indirect effects of logistics activities on society as a whole. Economic principles are well-suited for describing this concept and Harvey Rosen provides a useful definition of externalities:

> "When the activity of one entity (a person or a firm) directly affects the welfare of another in a way that is outside the market mechanism, that effect is called an externality."[2]

By this definition, externalities occur outside the typical market process, and therefore cause a form of market failure, since actors in the market do not incur the full costs of production and consumption. As a result members of the society may be negatively impacted by the activities for which the full social cost is not incurred. Of note is that the concept of externalities can also be applied to beneficial impacts; however in the case of transportation many of the significant externalities are negative.

The U.K. Round Table on Sustainable Development has summarized the externalities of logistics activities. Corresponding to the aforesaid common considerations for sustainability they have divided their list into similar categories. Table 3 provides an adapted version of their list.

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[1] [6] Browne and Allen (1999)
[2] [46] Rosen (2002)

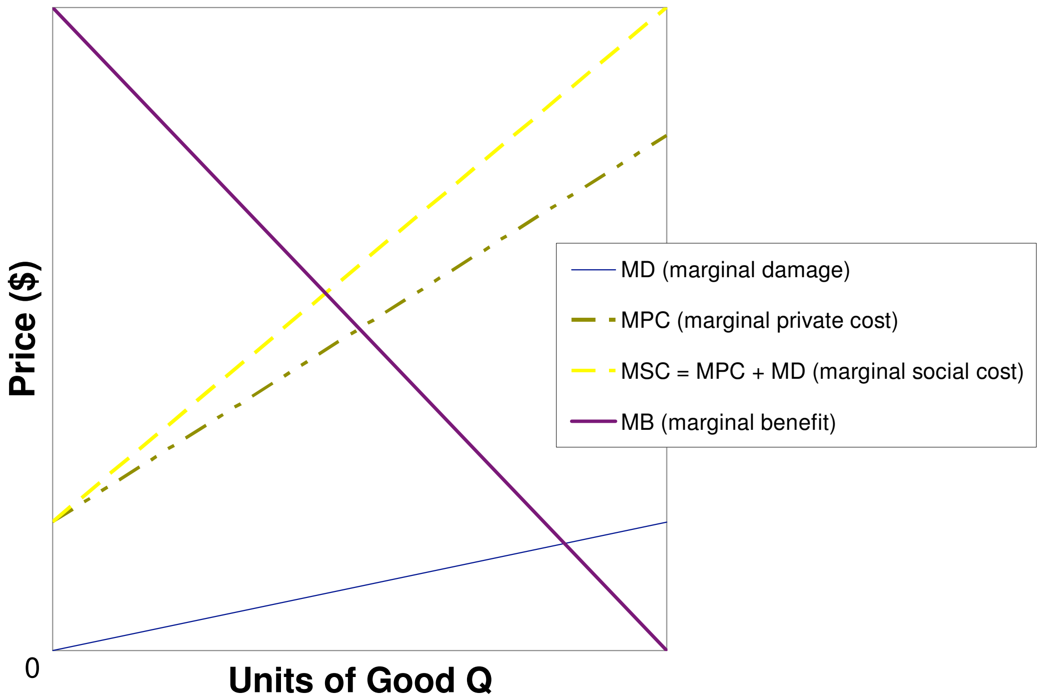
**Table 3 – Impacts of logistics systems.**
Source: Adapted from [66] UK Roundtable on Sustainable Development (1996)

| | |
|---|---|
| Economic Impacts | 1.Traffic Congestion<br>2. Resource waste |
| Ecological Impacts: | 1. Greenhouse Gases Cause Climate Change<br>2. The use of non-renewable fossil fuel<br>3. The effects of waste products such as tires and oil<br>4. Ecosystem destruction and species extinction |
| Social Impacts: | 1. Negative public health impacts of pollution<br>2. Crop destruction<br>3. Injuries and deaths resulting from traffic accidents<br>4. Noise<br>5. Visual intrusion<br>6. Congestion deterring passenger travel<br>7. Loss of Greenfield sites and open spaces<br>8. Deterioration of Buildings/Infrastructure |

Different categorization schemes could be used to organize these impacts, for instance climate change resulting from greenhouse gases has economic and social implications; however the importance of the list is that most of the negative externalities associated with logistics systems are included. It should be noted that designation of some of the listed items as externalities is debatable, as in the case of the use of non-renewable fuel.

Logistics providers are not typically forced to pay the full social cost of their activities, which includes the costs of the above listed externalities. Inefficiency results and the public is negatively impacted. As illustrated in Figure 1, without intervention logistics firms only pay the marginal private cost (MPC), resulting in market equilibrium conditions at which MPC equals the marginal benefit (MB). However the equilibrium point which maximizes social welfare occurs where the marginal social cost (MSC) equals MB, since MSC accounts for the combined cost incurred by the logistics companies and the general public.

**Figure 2 – Graphical representation of the externality problem.**
Source: Adapted from [46] Rosen (2002)




It should also noted that another topic of increasing importance is reverse logistics, which relates to the redistribution of new or used goods and materials to reduce the need for virgin production. However, because the objective is the reduction of impacts caused by production processes rather than those of distribution, reverse logistics will not be explicitly discussed in this paper. Instead, the focus will be on the movement of goods in forward logistics networks, for which the analyses will also have much applicability to reverse systems.

## 2.1. Externalities Resulting from Vehicle Emissions During Operations

Although most of the externalities listed in Table 3 could be categorized as environmental externalities, current environmental concerns are generally directed towards externalities resulting from vehicle emissions. As a result these impacts will be at the forefront of this document, although other notable impacts will also be discussed.

Diesel is the most commonly used fuel type in freight modes such as rail, marine and trucking. Unfortunately, diesel combustion products can also cause significant negative impacts at the regional level. The U.S. Environmental Protection Agency (EPA) has conducted a comprehensive health assessment of diesel engines. The following is a summary of their results. Gaseous components of diesel exhaust include carbon dioxide ($CO_2$), oxygen ($O_2$), water vapor, nitrogen ($N_2$), carbon monoxide (CO), nitrogen compounds, sulfur compounds and low-molecular-weight hydrocarbons. Particulate matter (PM) released include a central core of elemental carbon, adsorbed organic compounds, as well as small amounts of sulfate, nitrate, metals and other trace elements.

Nitrogen oxides ($NO_x$) and particulate matter tend to be of greatest concern due to their large constituency in diesel exhaust. A number of health-effects of diesel exhaust can be cited. Short-term effects include acute irritation, neurophysiological dysfunction, and respiratory problems. The long-term effects include damage to lung tissue and possibly lung cancer.[3] Other researchers have also addressed concerns over the effects of acid and smog formation. Acid deposition, which is caused primarily by $SO_2$, and $NO_x$, is a concern with regards to human health. Additionally, nitric acid ($HNO_3$), for which $NO_x$ is a precursor can cause paint deterioration, corrosion, degradation of buildings, and damage to agricultural crops. Furthermore, the combination of $NO_x$ with volatile organic compounds (VOC) and sunlight can cause the formation of photochemical smog, which impairs visibility and alters the taste and smell of air.[4]

At the global level climate change and stratospheric ozone ($O_3$) depletion are important concerns. $CO_2$, a greenhouse gas (GHG), is a product of fossil fuel combustion and therefore is released in diesel exhaust. Consequently freight transportation contributes sizably to GHG releases, and to effects on the global climate.[5] Global climate change is expected to drive the hydrological cycle more vigorously causing increases in the frequency and severity of storms, and drastic alterations to flood and drought patters.[6] In addition, ecosystems may be disrupted and ocean levels are expected to rise, potentially endangering the Earth's coastal inhabitants who make up a large proportion of the human and wildlife populations. Impacts of freight transportation on stratospheric ozone depletion are nearly negligible in comparison to other emissions sources; nevertheless it should be noted that older vehicles fitted with air conditioners or refrigerators, may release chloro-fluorocarbons (CFCs).[7] CFCs cause stratospheric $O_3$ depletion, subsequently increasing the amount of harmful ultra-violet radiation penetrating the Earth's atmosphere.

Aircraft, including those used for logistics operations are commonly powered by jet fuel. Emissions are composed of about 70% $CO_2$, close to 30% water vapor, and the rest made up of $NO_x$, CO, $SO_x$, volatile organic compounds and hazardous air pollutants.[8] Regional effects of the pollutants are fairly similar to those of diesel vehicles, but the global impacts are somewhat different due to the variations in altitude at which planes emit exhaust gases. Generally, exhaust from airplanes increases the quantity of GHG in the atmosphere, enhancing the effects of global warming and increasing $O_3$ concentration near the tropopause. However, as a result of differences in the atmospheric chemistry with variations in altitude, $O_3$ concentrations at higher levels of the stratosphere are expected to decrease due to aircraft emissions.

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[3] [62] U.S. Environmental Protection Agency (2002)
[4] [41] Nazaroff and Alvarez-Cohen (2001)
[5] [2] Ang-Olson and Ostria (2005)
[6] [41] Nazaroff and Alvarez-Cohen (2001)
[7] [15] European Conference of Ministers of Transport (1991)
[8] [64] U.S. Federal Aviation Administration (2005), p. 1.

## 2.2. Indirect Environmental Externalities

Rodrigue et al. note that "airports, seaports, and rail terminals are among the largest consumers of land in urban areas."[9] Construction and maintenance of such facilities requires polluting vehicles and equipment. Activities such as dredging, land-filling and the clearance of land for terminals also have significant environmental impacts, especially with regards to local wildlife. Another consideration is the links between terminals and their associated infrastructure. Horvath, et al. have utilized the method of Life Cycle Assessment (LCA) to analyze the environmental effects of roadways in the U.S., showing that the various economic sectors in the pavement supply chain are large contributors to pollution.[10] An LCA of freight transportation in the U.S. by Facanha and Horvath reveals significant impacts resulting from the construction and maintenance of links and facilities, the manufacturing of vehicles, and fuel provision which requires petroleum exploration, refining and distribution.[11] Still, the benefits gained as a result of installing logistics-supporting infrastructure are often perceived to outweigh that which is lost due to environmental impacts, especially in developing regions of the world. It should be noted that assessing infrastructure in terms of logistics systems can be a complicated task, since many of the facilities are concurrently used by passenger transportation modes.

As a result of increased congestion, freight transportation vehicles also affect the volume of pollutants emitted by other vehicles. In some cases congestion may actually decrease pollution by causing a reduction in average travel speeds; however, in slow-moving traffic, speed reductions cause significant increases to pollution.[12] Emissions associated with the effects of aggregate traffic flow would be requisite to a full estimation of environmental externalities.

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[9] [45] Rodrigue, Slack and Comtois (2001)
[10] [24] Horvath and Hendrickson (1998)
[11] [18] Facanha and Horvath (2006)
[12] [57] Transportation Research Board (1996)

## 3. The Problem of Environmental Externalities

The number of studies estimating the impacts of freight transportation on the environment continues to grow, revealing in greater detail the negative impacts which are occurring. Data from the U.S. and Europe indicate that the effects of emissions are significant and will continually increase if intervention is not made.

### 3.1. Emissions and Related Data

A fairly large body of data has been produced by various organizations, showing that freight logistics carriers are a significant source of pollutants causing environmental impacts. Some studies have analyzed the problem at the small-scale by generating data for individual vehicles, whereas others have focused on the net impacts of freight transport at national and international levels. From an even broader perspective, other researchers have assessed the long-term trends regarding the growth of demand and emissions from freight logistics networks.

#### 3.1.1. Emissions Data and Modal Considerations

Many estimates of emissions factors from heavy-duty vehicles are available, each having advantages and disadvantages with regards to the usefulness of results. Presented in Table 4 are the results of a study which compares the changes in average emissions factors in the U.S. over time by the most commonly employed measurement techniques. The decreasing values for emissions per fuel consumed are associated with improvements in technology and government regulations. It should be noted although trucks are the focus in this study, buses also comprise a small percentage of the vehicles sampled.

**Table 4 – Comparison of heavy-duty vehicle emissions factors by measurement methods over time.**
Source: Table 8 in [71] Yanowitz, McCormick and Graboski (2000)

| | chassis dynamometer tests[a] | | tunnel tests[b] | | remote sensing tests[b] | |
|---|---|---|---|---|---|---|
| pollutant | model years | (g/gal) | year | (g/gal) | year | (g/gal) |
| $NO_x$ (as $NO_2$) | all years[c] | 113 | 1992 | 111 | 1997 | 150 |
| | | | 1992 | 122 | 1997 | 108 |
| | | | 1992 | 125 | 1998 | 187 |
| | | | 1995 | 157 | 1998 | 81 |
| | | | 1996 | 129 | | |
| CO | 1982–1992 | 56 | 1992 | 78 | | |
| | | | 1992 | 78 | 1992 | 59 |
| | | | 1992 | 39 | | |
| | 1985–1995 | 51 | 1995 | 55 | | |
| | 1987–1997 | 46 | | | 1997 | 54 |
| | 1988–1998 | 44 | | | 1998 | 85 |
| | | | | | 1998 | 76 |
| THC | 1982–1992 | 8 | 1992 | 11 | | |
| | | | 1992 | 14 | | |
| | | | 1992 | 4 | | |
| | 1985–1995 | 7 | 1995 | -1 | | |
| PM | 1983–1993 | 6.2 | 1993 | 3.5 | | |
| | 1986–1996 | 5.1 | 1996 | 9.0 | | |
| | 1987–1997 | 5.1 | 1997 | 7.7 | | |

Fuel consumption and subsequently emissions as a result of on-road vehicle activity are a significant cause of environmental externalities; however another important consideration is off-road vehicle idling. Idling is wasteful, as it consumes fuel and emits pollutants while a vehicle is stationary. Many analysts in the trucking industry acknowledge the losses in fuel and subsequent costs of idling, but also state that it is a necessity. A quote from a trucking magazine summarizes the reasons for this problem:

> "Fleet managers can't expect drivers to sleep in an unheated or uncooled bunk, after all. Another scenario in northern climes has drivers fearing their engine won't start after just a few hours, so they leave it idling. In some cases of extreme cold, their fear is real — especially so if the hardware they depend on isn't well-maintained. Of course, there's laziness and maybe simple ignorance in the mix, as well."[1]

The U.S. Department of Energy estimates that over 800 million gallons of diesel fuel are consumed each year in the U.S. as a result of idling trucks. This study also shows that a single truck typically idles for about 1830 hours each year.[2] Results of another analysis conclude that about 34% of engine run time for long-haul trucks is spent idling and that around 41% of truck drivers do not take any steps to reduce their idle time.[3] From the industry perspective, one trucking company revealed that idling accounted for 50-60% of the time their truck engines are running.[4]

Although trucks tend to dominate the modal split for inland freight transportation in most regions, a comparison of emission factors versus marine and rail reveals that the latter two options may be favorable for many reasons. As can be seen in Table 5, on average trucks are found to have greater costs, fuel consumption, and emissions per ton-mile of freight transported. In addition, the values for rail indicate significantly greater costs and environmental impacts than those for marine transport by barge. These modal characteristics are of concern, since trucks and rail respectively dominate urban and intercity freight transport in the U.S. as shown in Figure 3 and Figure 4, and road transport tends to be the primary mode for inland freight movement in most European countries as presented in Figure 5.

**Table 5 – Comparison of emissions factors for barge, rail and trucks.**

Source [23] Grier (2002):, p.17.

| Shipping Rates | | Fuel Consumption Rates | | Emissions (lbs.) Produced in Moving 1 Ton of Cargo | | | |
|---|---|---|---|---|---|---|---|
| *Mode* | *Cents per ton-mile* | *Mode* | *Ton-miles per gallon* | *Mode* | *Hydrocarbon* | *Carbon Monoxide* | *Nitrous Oxide* |
| Barge | 0.97 | Barge | 514 | Towboat | 0.09 | 0.20 | 0.53 |
| Rail | 2.53 | Rail | 202 | Rail | 0.46 | 0.64 | 1.83 |
| Truck | 5.35 | Truck | 59 | Truck | 0.63 | 1.90 | 10.17 |

[1] [30] Lockwood (Dec. 1999)
[2] [8] Clean Cities Program (2005)
[3] [31] Lutsey, Brodrick, Sperling and Oglesby (2004)
[4] [30] Lockwood (Dec. 1999)

**Figure 3 – Mode split for intercity freight transportation by ton-miles in the U.S. in 2001**
Source: Figure 2-1 in [2] Ang-Olson and Ostria (2005)

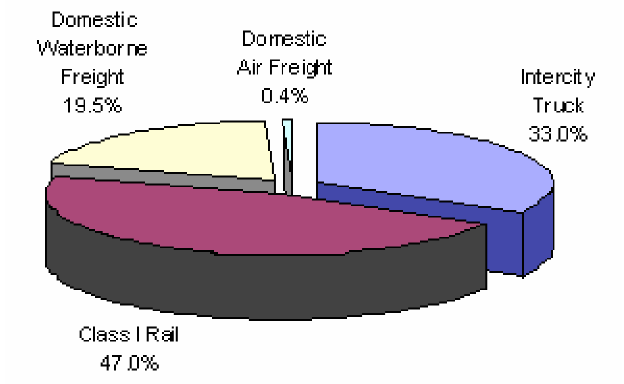



**Figure 4 – Mode split for overall freight transportation by tonnage in the U.S. in 2001**
Source: Figure 2-1 in [2] Ang-Olson and Ostria (2005)

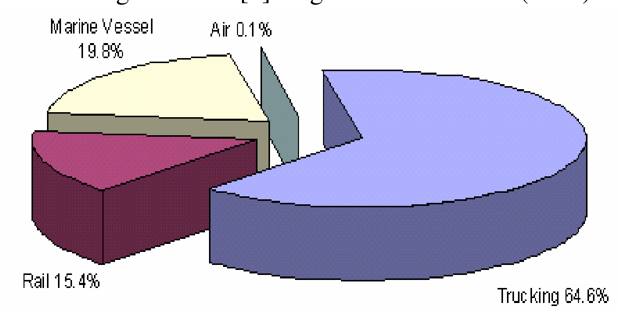
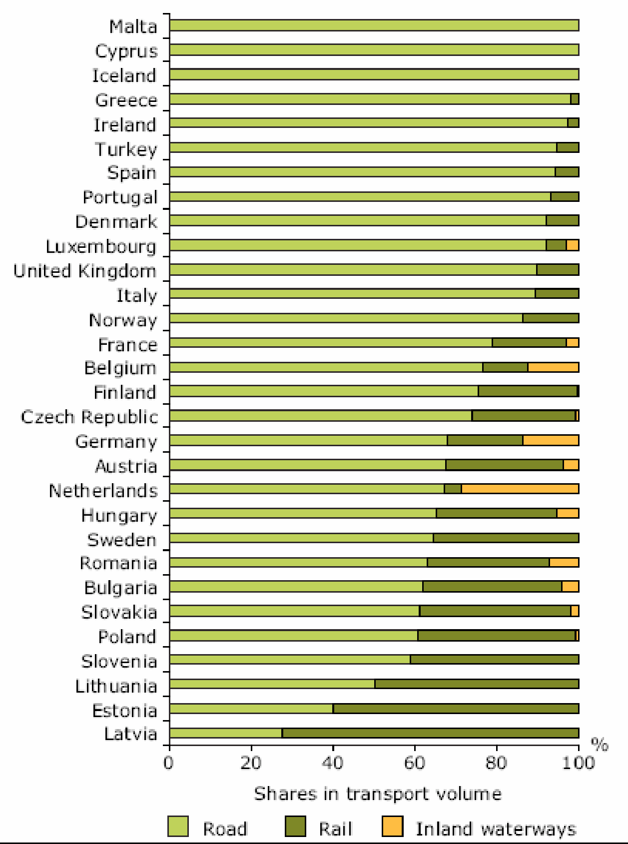


**Figure 5 – Modal split of freight transport volume**
Source: [16] European Environment Agency (2006)




In April of 2005 the U.S. Department of Transportation (USDOT) published a report, titled "Assessing the Effects of Freight Movement on Air Quality at the National and Regional Level".[5] Figure 6 through Figure 9 present the results of this report, showing the fraction of emissions caused by the freight movement in the U.S. The results indicate that emissions from freight transportation sources, especially in urban areas, are significant contributors to pollution at both the regional level and with regards to greenhouse gases. In addition, the primary mode causing pollutant emissions from freight transport is shown to be heavy-duty vehicles.

[5] [2] Ang-Olson and Ostria (2005)

**Figure 6 – Freight related emissions as a percentage of all U.S. sources.**
Source: Adapted from [2] Ang-Olson and Ostria (2005)

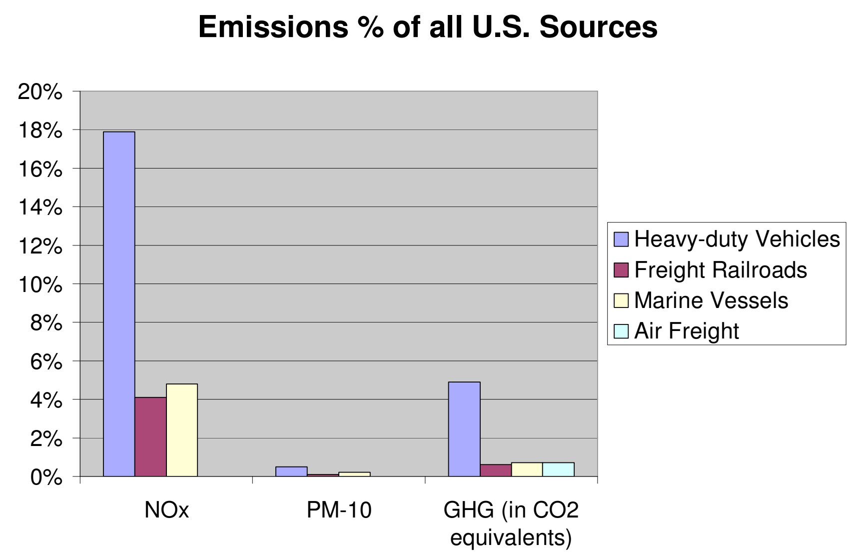



**Figure 7 – Freight related emissions as a percentage of U.S. transportation sources.**
Source: Adapted From [2] Ang-Olson and Ostria (2005)

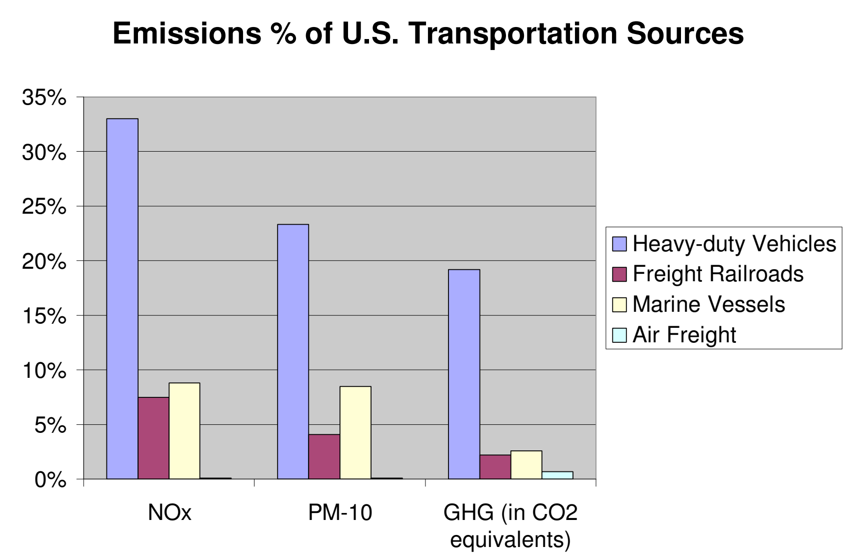


**Figure 8 – Regional freight related emissions as a percentage of all sources.**
Source: Adapted from [2] Ang-Olson and Ostria (2005)

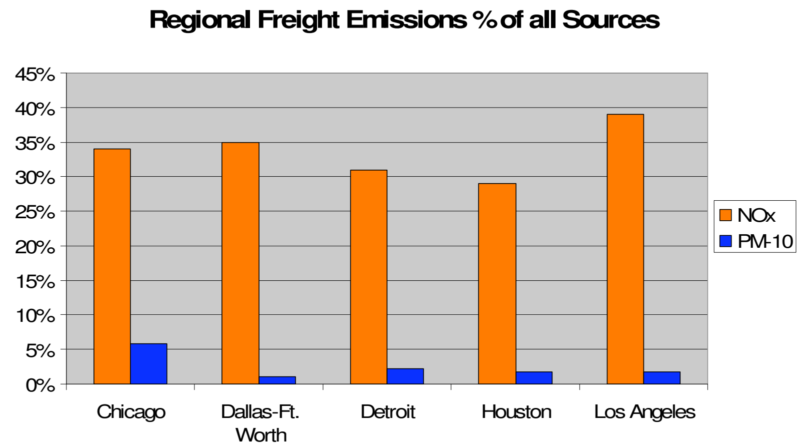
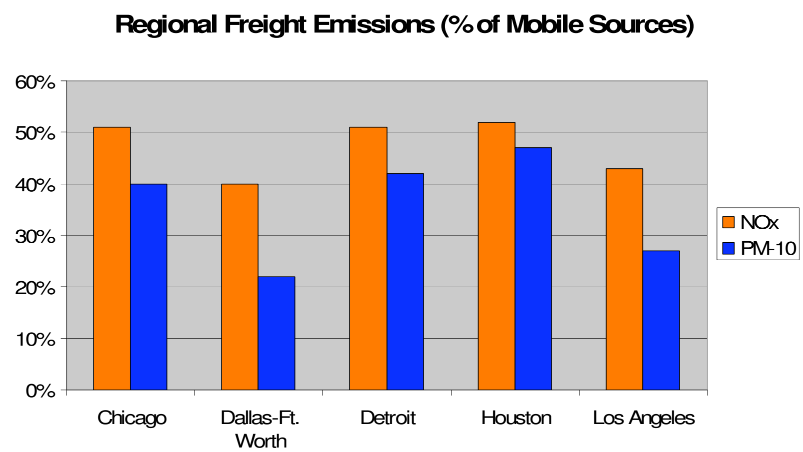



**Figure 9 – Regional freight related emissions as a percentage of mobile sources.**
Source: Adapted from [2] Ang-Olson and Ostria (2005)




### 3.1.2. Long-term Trends

Many studies have analyzed the long-term trends of freight transport. The results indicate that the amount of freight transported, and subsequently environmental externalities will continue to grow unless some shift in behavior is made. According to a paper published by the European Commission (EC), "unless major new measures are taken by 2010 in the European Union so that the Fifteen (countries) can use the advantages of each mode of transport more rationally, heavy goods vehicle traffic alone will increase by nearly 50 % over its 1998 level."[6] Vanek has analyzed air and sea modes used in freight transportation by predicting future growth in imports and exports for the U.S.[7] Some results of his research can be seen in Table 6. The row labeled "Combined" represents the total demand for freight movement in other countries as a result of U.S. imports and exports. Scenario 1 assumes that per capita income in developing countries

[6] [13] European Commission (2001)
[7] [67] Vanek (2001)

remains constant, Scenario 3 assumes that income becomes equivalent to that in the U.S., and Scenario 2 makes a middle estimate.

**Table 6 – Projected growth in energy consumption in the U.S. as a result of imports and exports.**
Source: Table 2 in [67] Vanek (2001)

| | Tonne-km, in billions | | Energy, in ExaJoules (10e18 J) | | |
|---|---|---|---|---|---|
| | Air | Sea | Air | Sea | Total |
| 1995 estimates | | | | | |
| USA[a] | 18.0 | 3011 | 0.26 | 0.37 | 0.63 |
| Combined LDCs | 31.9 | 5329 | 0.46 | 0.66 | 1.12 |
| 2045 estimates for combined LDCs | | | | | |
| Scenario 1 | 71.4 | 11934 | 1.03 | 1.48 | 2.51 |
| Scenario 2 | 376 | 62855 | 5.40 | 7.80 | 13.20 |
| Scenario 3 | 680 | 113775 | 9.78 | 14.12 | 23.90 |

[a]USA value is for 1994, due to lack of 1995 data.

The USDOT has also compiled a list of projections categorized by mode and based on annual growth rate. Table 7 presents forecasts that have been produced in studies by the U.S Bureau of Transportation Statistics (BTS), the American Association of State Highway and Transportation Officials (AASHTO), the American Trucking Association (ATA), and ICF Consulting (ICF).

**Table 7 – U.S. domestic freight demand projections.**
Source: [2] Ang-Olson and Ostria (2005)

| | Historic Data | Forecasts (compound annual growth rate) | | | |
|---|---|---|---|---|---|
| | (ann. growth) | BTS | AASHTO | ATA | ICF |
| | (ton-miles) | (ton-miles) | (ton-miles) | (tons) | (ton-miles) |
| | 1990-2000 | 2000-2025 | 2000-2020 | 2002-2014 | 2000-2020 |
| Truck | 3.9%[a] | 2.6% [a] | 2.3% | 2.2% | 2.5% |
| Rail | 3.6% | 0.2% | 1.9% | 1.7% | 2.0% |
| Water | -2.5% | | 0.7% | 1.6% | 0.7% |
| Air | 5.2% | 3.1% | 5.7% | 4.4% | 4.0% |

Similar estimates have been made for European freight transport growth. In the last decade significant growth in freight traffic volume along with GDP have occurred in countries comprising the European Environment Agency (EEA). As a result the EC goal of decoupling freight transport volume growth from GDP has not been achieved.[8] In fact, decoupling freight transport demand from economic activity and international trade has been described as an unattainable utopia.[9] Figure 10 represents this trend as the two curves along with the left axis represent GDP and freight transport volume shifts. In addition, the right axis and bar chart indicate the percent decline in transport intensity since the previous year. Freight transport intensity is defined by the EEA as the ratio

[8] [16] European Environment Agency (2006)
[9] [38] Meersman and Van de Voorde (2005)

between ton-km traveled to euros GDP for inland goods movement. Another, more direct descriptor for the growing environmental problems caused by freight movement is emissions data. Results of one such study are presented in Table 8, showing increases in the release of greenhouse gas emissions in the UK by the road freight industry.

**Figure 10 – Freight transport volume growth with GDP.**
Source: [16] European Environment Agency (2006)

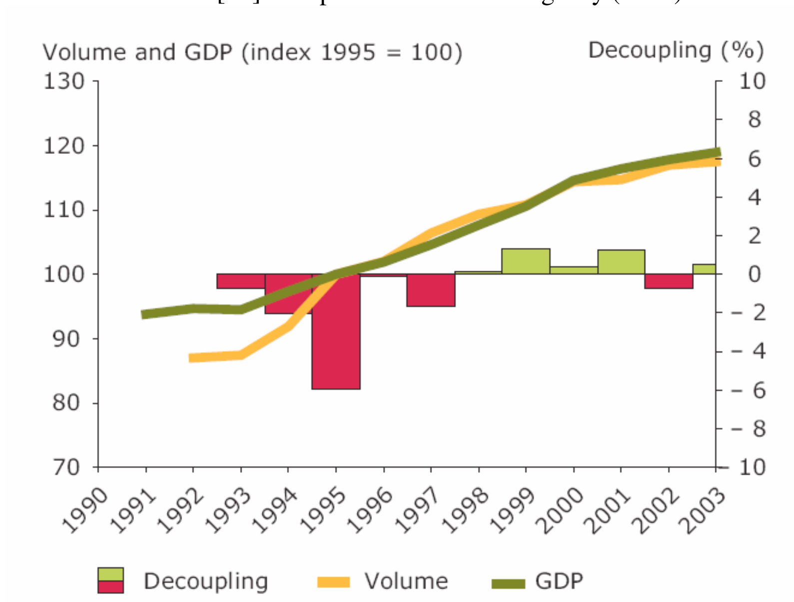



**Table 8 – Greenhouse has emissions from the UK road freight industry**
Source: Table 3 in [60] U.K. Office for National Statistics (2004)

Million tonnes of $CO_2$ equivalent

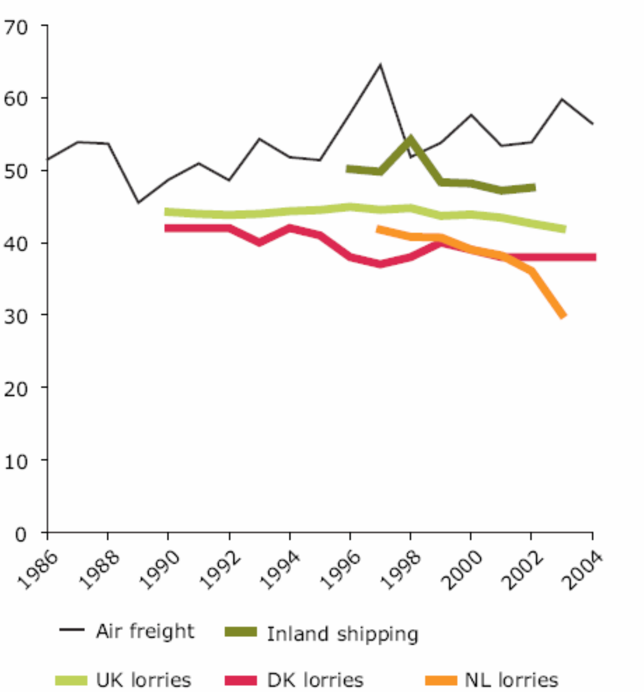
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heavy goods vehicles | | | | | | | | | | | | | |
| - articulated | 10.4 | 10.0 | 9.9 | 11.1 | 12.8 | 13.8 | 15.1 | 15.8 | 16.2 | 16.1 | 16.0 | 16.9 | 17.3 |
| - rigid | 4.5 | 4.1 | 4.2 | 4.0 | 4.1 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.1 | 4.2 | 4.3 |
| Total HGVs[1] | 14.9 | 14.1 | 14.1 | 15.1 | 16.9 | 17.8 | 19.1 | 19.8 | 20.2 | 20.1 | 20.1 | 21.1 | 21.6 |
| Non-HGV sources | 0.9 | 0.9 | 1.0 | 1.1 | 1.2 | 1.4 | 1.4 | 1.5 | 1.4 | 1.6 | 1.6 | 2.0 | 1.8 |
| **Total** | **15.8** | **15.1** | **15.1** | **16.3** | **18.1** | **19.2** | **20.5** | **21.3** | **21.6** | **21.7** | **21.8** | **23.0** | **23.4** |

**Percentage change from 1990**

| | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heavy goods vehicles | | | | | | | | | | | | |
| - articulated | -4% | -5% | 7% | 22% | 32% | 45% | 52% | 55% | 54% | 54% | 62% | 66% |
| - rigid | -8% | -7% | -11% | -8% | -11% | -11% | -12% | -12% | -10% | -9% | -6% | -4% |
| Total HGVs | -5% | -6% | 1% | 13% | 19% | 28% | 33% | 35% | 35% | 35% | 41% | 45% |
| All non-HGV sources | 9% | 13% | 29% | 44% | 58% | 59% | 70% | 67% | 79% | 88% | 127% | 110% |
| **Total** | **-5%** | **-4%** | **3%** | **15%** | **21%** | **29%** | **35%** | **37%** | **37%** | **38%** | **46%** | **48%** |

Vehicle under-utilization has been cited as an indicator of excessive freight transport vehicle use. The problem is generally addressed in terms of empty running and load factor considerations. Load factor represents the percentage of capacity, measured in weight or volume, which is utilized in vehicles and empty running describes the case in which this factor is zero. These under-capacity trips impose excess costs on freight companies, making vehicle under-utilization a commonly discussed problem in industry. Additionally, from an environmental perspective, under-utilization causes greater emissions than the case in which full-utilization is achieved due to the additional trips being made. As displayed in Figure 11, European freight vehicles are found to have fairly low and declining load factors by weight, with the exception of air transport. According to McKinnon, empty running is estimated to constitute about 25% of freight vehicle-miles traveled in the U.K.[10] Causes of empty-running include geographical demand imbalance, scheduling constraints, and vehicle incompatibility.

**Figure 11 – Average load factors in Europe based on weight.**
**UK - United Kingdom, DK - Denmark, NL - Netherlands**
Source: [16] European Environment Agency (2006)




## 3.2. Data Regarding Indirect Impacts

The LCA by Facanha and Horvath regarding pollutant releases resulting from freight transportation in the U.S. allows for a comparison between truck, rail and air modes across various phases of their life-cycles. The focus of their work is on long distance goods movement, with the exclusion of the last-mile from the analysis. The following figures show that rail transportation is the least polluting mode per ton-mile for the four considered pollutants and that a fair proportion of emissions occur outside the operational phase. Nevertheless, most of the pollution results from fuel combustion, thus a study geared towards reducing externalities during the operational phase of the life-cycle could provide the most immediate mitigation solutions. Figure 12 provides life-cycle emissions factors and Figure 13 displays the ratio of total pollution released to that resulting from fuel combustion.

[10] [34] McKinnon (2003)

**Figure 12 –Modal comparison for life-cycle emissions.**
Source: Figure 1 in [18] Facanha and Horvath (2006)

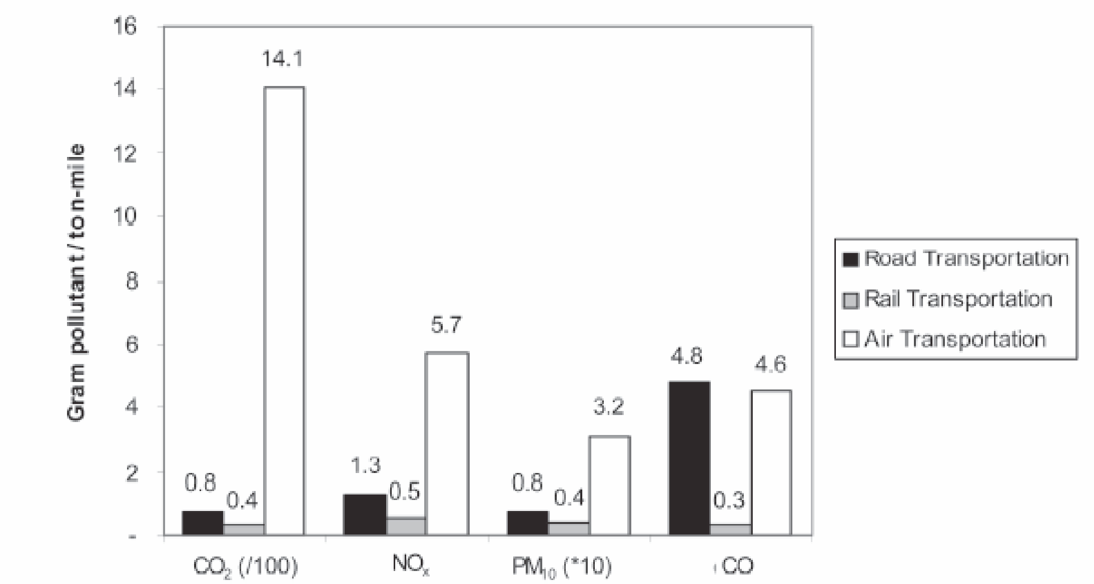
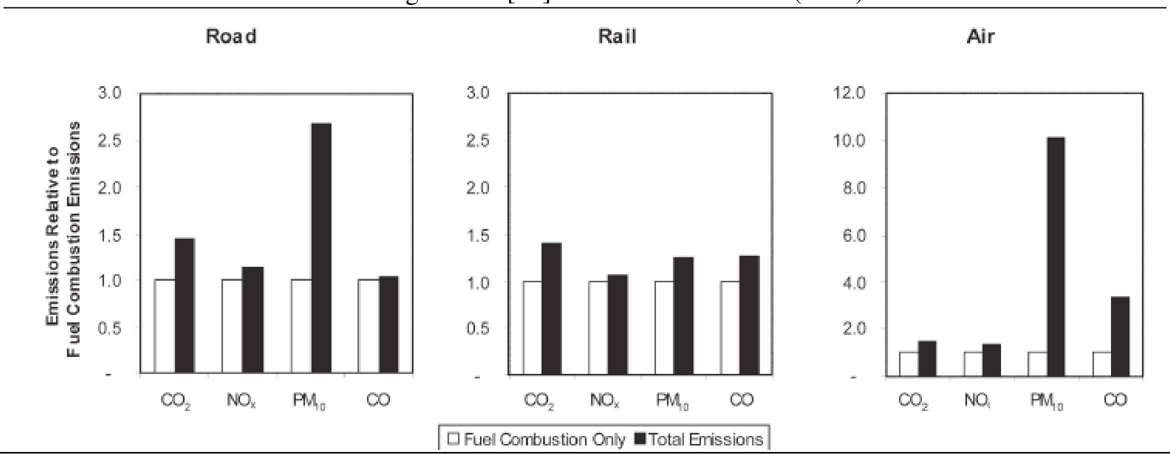



**Figure 13 – Comparison between life-cycle and fuel combustion emissions.**
Source: Figure 3 in [18] Facanha and Horvath (2006)




## 3.3. Quantifying Environmental Externalities

Most previous studies which address the quantification of environmental externalities focus on transportation in general. These include research by Small et al.[11] and Matthews et al.[12], which quantify the overall effects of transportation externalities. However, a handful focuses on the estimation of the impacts of freight logistics networks. In general the quantification of environmental externalities can be divided into two aspects. The first being the determination of the relevant emissions released with some with some unit of measure, such as tons. The second aspects is to apply a damage factor which might be in units such as $/ton of a pollutant. Damage considerations could include effects such as

[11] [49] Small and Kazimi (1995)
[12] [33] Matthews, Hendrickson and Horvath (2001)

human health, loss of wildlife, agricultural failure, and global warming. The damage factor must be carefully assessed, since it depends greatly on the context of the society and setting of impact. For example one could, in the interest of international goodwill, consider global warming as an element of the damage factor; however the impact of global warming might be miniscule for a particular region, and thus the analyst might choose to exclude global warming. The accuracy of the damage factor might also suffer due to an assumption of linearity. For instance the damage of a pollutant may be nearly nonexistent below a certain emissions threshold when human health is considered, limiting the validity of the factor across the range of possible emissions values. Such problems are inescapable when quantifying externalities; nevertheless approximations have been made for the impacts of freight logistics.

The National Research Council of the Transportation Research Board (TRB) has developed a framework for estimating the social cost of freight transportation including environmental externalities.[13] Their methods account for external impacts related to infrastructure, congestion, accidents, air pollution, petroleum consumption, noise and user fees. Air pollution is assessed at the regional level, using criteria such as the value of life, the costs of human exposure to pollution and the health costs of fugitive dust emissions. However, of note is the fact that this methodology does not include global impacts or a comprehensive analysis of regional health effects.

Another scheme for assessing external effects is ExternE, which has been developed for the EC. The damage types assessed are broader than those of TRB, including health considerations such as mortality and morbidity, along with the effects on building materials, crops, noise, ecosystem disruption and global warming. Applications include comparisons between the costs of various fuels and the estimation of the environmental costs of lorries for freight logistics in the U.K.[14] In another case, researchers applied ExternE to study Belgian interurban freight traffic. Their published results include cost estimates of air pollution on a modal basis.[15] Table 9 displays the results which show that pollution from interurban freight movement is extremely costly in Belgium.

**Table 9 – External costs of pollution for interurban freight transportation in Belgium.**
Source: Adapted from [5] Beuthe, Degrandsart, Geerts and Jourquin (2002)

| | Cost per Freight Movement ($10^6$ Euros/ton-km) | Total Cost ($10^6$ Euros) |
|---|---|---|
| Road | 18.2 | 571 |
| Rail | 5 | 36 |
| Waterway | 9.8 | 54.8 |

Similar research has been conducted by David Forkenbrock with regards to intercity freight transportation in the U.S. His methods combine the quantification techniques developed by National Economic Research Associates (NERA) and National Research Council (NRC) to estimate dollar costs per mass of emitted pollutants.[16] The NERA has

[13] [57] Transportation Research Board (1996)
[14] [14] European Commission (2005)
[15] [5] Beuthe, Degrandsart, Geerts and Jourquin (2002)
[16] [19] Forkenbrock (1999)

accounted for adverse effects on health, materials, agriculture, and aesthetic quality for producing pollutant cost estimates for VOCs, $NO_x$, $SO_x$, and $PM_{10}$ in a representative sample of counties in the U.S. The results of an NRC study have been used for estimating the cost of $CO_2$, which is distinguished from the other pollutants because of its affect on climate change. Table 10 summarizes the results of this study. The costs may seem small, but are justified by Forkenbrock who states that most intercity transportation in the U.S. occurs in rural areas, where population density and subsequently impacts on humans are relatively low. Additionally, Forkenbrock has published a comparison of the external costs of truck and rail freight transportation in the U.S. overall. Similar results are derived on a dollar per ton-mile basis for freight movement using these two modes.[17]

**Table 10 – Costs of pollution as a result of intercity freight transportation in the U.S.**

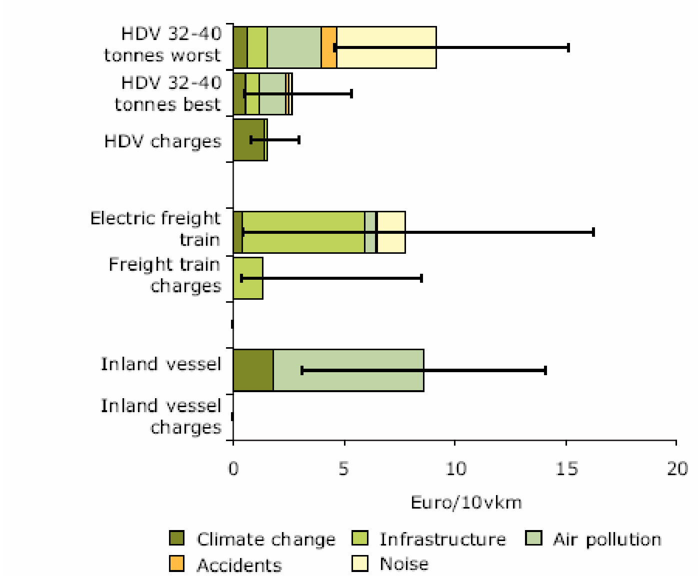
Source: Adapted from [19] Forkenbrock (1999)

| Pollutant | Cost per ton-mile (cents) |
|---|---|
| VOC | 0.04 |
| $NO_x$ | 0.032 |
| $SO_x$ | 0.01 |
| $PM_{10}$ | 0.045 |
| $CO_2$ | 0.015 |

The external costs and contributions by mode have also been estimated for freight transport across Europe. Figure 14 displays these results, along with error bars representing the range between the minimum and maximum possible costs. This variation is a result of the variable factors affecting impacts, including proximity to urban areas and traffic congestion levels.

**Figure 14 – External costs in Europe by mode.**

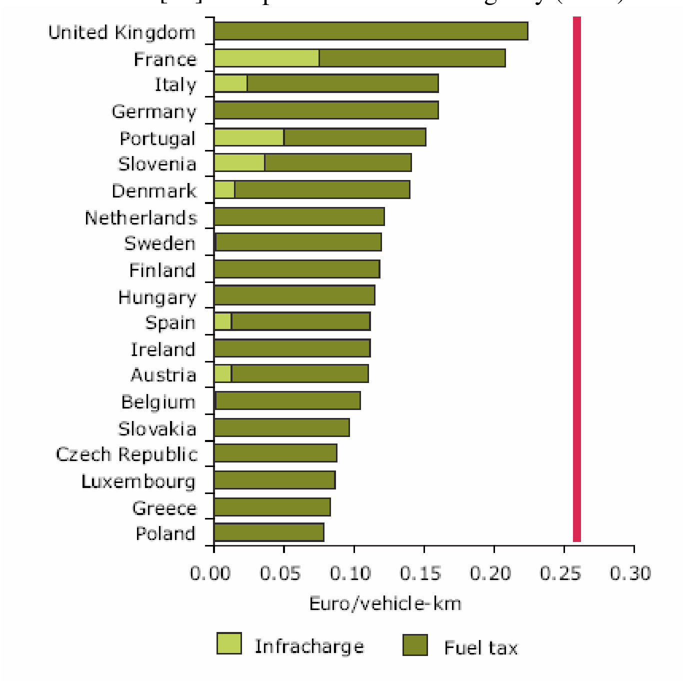
Source: [16] European Environment Agency (2006)




[17] [20] Forkenbrock (2001)

Comparisons have been made between the distance related charges incurred by road freight transport carriers versus a minimum estimate of external costs. This estimate, represented by the red line in Figure 15, is based on transportation along a rural roadway which has few accidents, and can likely be attributed in large part to environmental externalities, in accordance with Figure 14. The charges are derived based on fees for infrastructure and fuel. As can be seen in Figure 15, distance related charges to freight companies fall far below the estimated marginal external costs in most European countries.

**Figure 15 – Distance related charges for road freight transport in Europe.**
Source: [16] European Environment Agency (2006)



## 4. Options for Reducing Environmental Externalities

A fair assemblage of previous research can be found related to Green Logistics solutions with regards to facets such as industry practices, technology, operations, public projects and governmental policies.  Within the context of sustainability, environmental effects are the prime consideration of these solutions; however economic effects are a requisite measure for feasibility.  To some extent social outcomes can be assumed to have strong correlation with the environmental and economic.  Although social consequences are important, they will not be the focus of this document.  Green logistics solutions can be divided into four categories as shown in Table 11, ranging from those which are least likely to have economic consequences through those which may have significant impact on the freight logistics sector along with associated aspects of the economy and society. The first set of effects, denoted by Roman numeral I, comprises of concepts which could lead to solutions having negligible effect on the activity level in the freight sector, since impact mitigation is the focus, rather than emissions.  The second set would cause emissions reductions for individual vehicles, thus having little direct effect on activity levels.  On the other hand, the options and considerations categorized under the third set require significant changes in freight sector operations, likely reducing vehicle-miles traveled along with emissions.  As a result the general activity level of the freight sector could be significantly impacted.  The final set, denoted by IV, encompasses concepts and methods geared at influencing environmental externalities by considering demand in the context of economics and culture.  As a result these ideas would have broad implications on society as a whole.  The reader should note that this list is not meant to be entirely comprehensive, but provides a summary of salient options for Green Logistics based on previous research.

**Table 11 – Overview of options for reducing environmental externalities.**

| Solution Types for Affecting Externalities | Application Types | Options/Considerations |
|---|---|---|
| I. Impact Reduction | A. Impact Assessment | 1. Exposure Metrics |
| | B. Policies and Projects | 1. Diversion based on location<br>2. Diversion based on timing |
| II. Emissions Reduction | A. Industry Practices | 1. Employee Training<br>2. Equipment Condition |
| | B. Technologies | 1. Fuel Efficiency<br>2. Fuel Changes<br>3. Combustion Improvements<br>4. Post-Combustion Controls |
| | C. Government Policies | 1. Vehicle Standards<br>2. Fuel Standards |
| III. Changing Operations | A. Technologies | 1. Intelligent Routing Systems<br>2. Real-Time Traffic Information<br>3. Online B2B Coordination |
| | B. Operations | 1. Vehicle Utilization<br>2. Intermodal Options |
| | C. Public Projects | 1. Terminals<br>2. Pavement Characteristics |
| | D. Government Policies | 1. Load Factor Requirements<br>2. Weight Regulations<br>3. Zonal Designations<br>4. Temporal Restrictions<br>5. Taxation<br>6. Market Creation |
| IV. Economic and Societal Development Considerations | A. Demand | 1. Goods Characteristics<br>2. Geography<br>3. Cultural |

## 4.1. Impact Considerations

The process leading to environmental externalities can be divided into two aspects: the cause and the effect, in which one can think of the former as emissions and the latter as their impacts. Thus methods can be developed for reducing environmental externalities by focusing on impact reduction, regardless of gross exhaust emissions levels. For example heavily polluting industries in the U.S. are typically prohibited from opening facilities near residential areas. This measure does not necessarily effect emissions, but geographically separates them from the residents in an effort to maintain health standards. The influence of such solutions could be measured by the reduction in external costs from freight transport which, as aforestated, are comprised of a significant environmental externalities component.

### 4.1.1. Impact Assessment

Determination of methods for diverting emissions away from high-impact settings requires some quantification measure of impacts. Several metrics for determining the impacts of emissions have been developed. Examples include toxicity potential, acidification and intake fraction. Such measures can be used as a basis for assessing methods which might reduce the impacts of logistics systems. For instance, intake fraction represents the ratio of the quantity of a pollutant taken in by people to that which is emitted. As a result if the equivalent amounts of a pollutant are released in both an urban and a rural area, the low population density of the latter is likely to also be associated with a low intake fraction and negative health effects. Once the fraction is determined, it could then be translated into a monetary value in the case that a measure for external costs is a useful analysis tool.

**Intake Fraction -**

Source: [32] Marshall, Teoh and Nazaroff (2005)

$$\text{Intake Fraction (iF)} = \frac{\text{Population Intake}}{\text{Total Emissions}} = \frac{\int_{T_1}^{\infty}\left(\sum_{i=1}^{P}(C_i(t)\cdot Q_i(t))\right)\mathrm{d}t}{\int_{T_1}^{T_2} E(t)\,\mathrm{d}t}.$$

*where:*

*$T_1$ and $T_2$ are the starting and ending times of an emissions process*

*P = the number of people in the exposed population*

*$Q_i(t)$ = the breathing rate ($m^3/s$) for individual i at time t*

*$C_i(t)$ = the incremental concentration ($g/m^3$) at time t in individual i's breathing zone that is attributable to the emissions process*

*E(t) is the emission rate from the process (g/s) at time t*

### 4.1.2. Governmental Instruments

A decrease in externalities could be achieved by limiting vehicle operations to low-impacting times and locations, which would generally be influenced by government regulations. As will be discussed in the following sections, such considerations have already been accounted for with regards to congestion, meliorating an extension to include environmental impacts. Options such as strategic placement of public terminals, and travel restriction zones could be employed to divert freight vehicle traffic and emissions away from densely populated areas and fragile ecosystems. In addition, timing restrictions imposed by regional governmental bodies could allow for diversion of emissions to nighttime hours, when breathing rates and the population in urban areas tend to be minimal. However, such methods should be carefully analyzed due to the complexity of the natural systems which effect pollutant behavior. For example, $NO_x$ chemistry shows that an increase in $NO_2$ concentrations in the atmosphere during the night can cause the formation of nitric acid, and subsequently acid rain, potentially negating the benefits of nighttime restrictions. In addition, wind patterns and atmospheric reactions greatly effect regional pollutant dispersion.

## 4.2. Options Focused at Emissions Reduction

In the case that impact reduction methods are insufficient for reducing environmental externalities, multiple methods exist which could significantly reduce emissions by affecting their causes. Amongst these methods, many can be applied to reduce emissions factors without significantly affecting logistics operations, and as shown in Table 2, have also contributed to significant improvements in recent decades. As a result these methods are likely to be more readily accepted by industry. Additionally, measurement techniques are already being employed to determine emissions factors, thus the development of monitoring systems should be practicable. As shown in Table 11, the options can be categorized by industry practices, technologies and governmental policies.

### 4.2.1. Industry Practices

Employee training is a simple and effective method for reducing fuel consumption and subsequently emissions from trucks. Ang-Olsen and Schroeer describe several ways by which employees can improve the fuel economy of trucks:[1] For example, by reducing drag forces, fuel consumption can be immediately impacted. Some options for decreasing the aerodynamic drag of trucks include reducing the tractor-trailer gap, securing loose tarpaulins, and closing the curtains on empty trailers. In addition, flatbed trailer cargo should be kept as low and consistent as possible. Drivers can reduce fuel consumption through acceleration and shifting techniques, and by limiting average speeds, idling time, accessory usage, and the number of stops made. Furthermore, companies can motivate these practices by monitoring fuel consumption and providing driver incentives. Employee training has a strong chance of being widely accepted by companies, since it offers the opportunity for companies to save costs with relatively simple adjustments while reducing emissions.

A high standard of equipment performance can improve fuel efficiency and reduce environmental impacts.[2] Such standards should be applied not only to transportation vehicles such as trucks and ships, but also at terminals where equipment, including cranes and forklifts are often used. The salient concerns when assessing performance are age and maintenance practices.

### 4.2.2. Technologies for Affecting Emissions Factors

Technology is the catalyst for many changes in modern transportation systems. Logistics networks are no different in this respect as evidenced by research results presented by the Organisation for Economic Cooperation and Development, which completed a five-year initiative to assess Environmental Sustainability in Transport (EST). Their projections indicate that amongst various possible solutions, technology will contribute to 46% of the improvement needed to meet their specified EST criteria by 2030.[3]

Rising energy prices are causing companies to consider technological options which can decrease fuel consumption, and in turn reduce emissions factors. Combustion of fuels by vehicles on roadways generates energy to overcome drive train friction, aerodynamic

[1] [3] Ang-Olson and Schroeer (2002)
[2] [2] Ang-Olson and Ostria (2005)
[3] [7] Caid, Crist, Gilbert and Wiederkehr (2002)

drag, rolling resistance, operation of vehicle accessories, and inertial forces for acceleration or climbing. Table 12 provides an overview of the technological advances which could be applied to logistics vehicles to improve fuel efficiency for overcoming the latter four of the listed resistance forces.[4]

**Table 12 – Overview of technological options for reducing fuel consumption by trucks.**
Source: Adapted from [3] Ang-Olson and Schroeer (2002)

| Energy Requirement Factor | Options for Improving Fuel Economy |
|---|---|
| Aerodynamic Drag | • Tractor Devices:<br>o Roof Deflectors<br>o Cab Devices<br>o Side Fairings<br>o Front Air Dam<br>• Tractor Devices<br>o Trailer Side Skirts and Fairings<br>o Plastic Pieces Mounted to create a vortex in the tractor-trailer gap and behind the trailer |
| Rolling Resistance | • Wide-Base Tires<br>• Automatic Tire Inflation Systems<br>• Tare Weight Reduction |
| Drive Train Friction | • Low-Viscosity Lubricants |

Table 13 summarizes the technology options for reducing energy consumption and off-road emissions factors, resulting from overnight vehicle idling.[5] Each reduces fuel consumption, but also has an associated tradeoff as other causes of emissions and costs are increased. Such costs may pose a barrier to voluntary industry acceptance.

[4] [3] Ang-Olson and Schroeer (2002)
[5] [50] Stodolsky, Gaines and Vyas (2000)

**Table 13 – Technology options for reducing overnight diesel engine idling.**
Source: Table 2 in [50] Stodolsky, Gaines and Vyas (2000)

| Technology | Function | Benefits | Drawbacks | Technology Status |
|---|---|---|---|---|
| Direct-fired heater | Heating for cab/sleeper and/or engine. | Can be used at any stop for heating. Small and lightweight. | Cannot provide cooling. Requires battery power and may be unreliable when not equipped with automatic engine starting.[b] | Commercial. |
| Auxiliary power unit | Heating and air-conditioning of cab/sleeper, heat for engine, and power for auxiliaries. | Can be used at any stop for heating, cooling, and auxiliaries. Recovers waste heat for space heating. Serves as survival system. | Heavier and larger than direct-fired heater. May require separate sleeper air conditioner. | Commercial. |
| Thermal storage | Heating and air-conditioning for cab/sleeper only. | Driver comfort. | Does not heat engine. Requires relatively large space for storage medium. Performance dependent on truck use. | At or near-commercial. Commercial in other applications. |
| Direct heat with thermal storage cooling | Heating and air-conditioning of cab/sleeper and heat for engine. | Can be used at any stop for heating and cooling. | Requires battery power. | Commercial. |
| Truck stop electrification | Provides electricity for heating, air-conditioning, and auxiliaries. | Provides power for heating and cooling and auxiliaries. | Limited choice of over-night location. Requires separate sleeper air conditioner and electrically powered heater. Requires infrastructure at the truck stop. | Not commercial. Commercial in other applications. |

Emissions factors for modes other than trucks were given in Section 3, and corresponding methods have been studied for reducing their fuel consumption. Table 14 provides a summary of the important methods for increasing fuel economy for non-road modes. Most are similar to those displayed in Table 12 in that their aim is to reduce the energy required to overcome resistance forces.

**Table 14 – Overview of options for reducing fuel consumption for non-road modes.**
Source: Adapted from [2] Ang-Olson and Ostria (2005)

| Mode | Options for Improving Fuel Economy |
|---|---|
| Rail | • Tare Weight Reduction<br>• Low-Friction Bearings<br>• Steerable Rail Car Trucks<br>• Improved Lubricants |
| Marine | • Larger Vessels<br>• Improved Hull Design |
| Air | • Aerodynamic Improvements<br>• Lighter Weight Materials<br>• More Efficient Engines |

#### 4.2.3. Technology Options Related to Combustion Processes

Vehicles play an important role in fuel consumption; however combustion processes are central to affecting pollution. Options exist for reducing pollutant emissions before, during and after combustion. Pre-combustion modifications to fuel can be beneficial, as many energy analysts predict that global petroleum prices will continue to rise, making alternative fuels a cost-effective option for powering freight vehicles. A switch to alternative fuels could significantly decrease vehicle emission factors, as many cause lower emissions than diesel combustion. However, a tradeoff arises as some also have lower fuel efficiency or power output. Table 15 contains examples of some alternative fuels which are being researched or have already been implemented. Another option is hybrid electric vehicles, which may become cost-effective in the future, especially in urban areas where trucks commonly travel short routes on surface streets.[6] Test studies using electric vehicles in Rotterdam and Osaka have revealed a strong potential for their acceptance.[7]

**Table 15 –Examples of alternative fuels to diesel.**
Source: Adapted from [2] Ang-Olson and Ostria (2005)

| Fuel | Considerations |
|---|---|
| Emulsified Diesel | • 17-20% Decrease for $NO_x$ emissions<br>• 17-50% Decrease for PM emissions<br>• Increase for VOC<br>• Reduction in fuel economy |
| Biodiesel | • Increase for $NO_x$ emissions<br>• Decrease for PM, CO, hydrocarbons, air toxics |
| Natural Gas | • Does not decrease GHG emissions<br>• Storage and safe handling difficulties |
| Propane | • Decreases NOx and PM emissions by 80%<br>• Does not decrease GHG emissions |
| Ethanol-Diesel Mix | • Rare usage only currently |

In addition to changes which can be made to fuels, options affecting combustion process are also viable. The EPA lists many engine improvements which can reduce emissions. Amongst these options, those which have been described by the EPA as "needed to comply with new emissions standards", are listed below. Such technologies generally reduce pollution by increasing the potential for complete fuel combustion, resulting in lower emissions factors:[8]

1. Cooled exhaust gas recirculation
2. Combustion optimization
3. Improved fuel injection
4. Variable geometry turbochargers
5. Onboard diagnostics

The final set of options related to engine processes is post-combustion emissions treatment. Some of these are listed in Table 16, where it can be seen that many possibilities are becoming available for reducing $NO_x$ and PM emissions from diesel exhaust.

6 [28] Langer (2004)
7 [21] Geroliminis and Daganzo (2005)
8 [61] U.S. Environmental Protection Agency (2000)

**Table 16 –Examples of post-combustion treatment mechanisms.**
Source: Adapted from [2] Ang-Olson and Ostria (2005)

| Fuel | Considerations |
|---|---|
| Diesel Oxidation Catalysts | • Does not decrease $NO_x$ emissions<br>• Reduces PM emissions |
| Diesel Particulate Filters | • Can only be used with low-sulfur diesel<br>• Does not decrease $NO_x$ emissions<br>• 50-90% Decrease for PM emissions |
| NOx Catalysts | • 10-20% Decrease for $NO_x$ emissions<br>• 70% Decrease for $NO_x$ emissions when using ultra-low sulfur diesel |
| Selective Catalytic Reduction | • 75-90% Decrease in $NO_x$ emissions<br>• 20-30% Decrease in PM emissions |

### 4.2.4. Government Standards

Unfortunately voluntary use of such control devices seems unlikely. As a result regulation is a commonly employed policy option for reducing emissions. As with externalities, significant economic analysis has been conducted regarding regulations in general. From an economic standpoint, regulations often cause market inefficiencies, since they enforce a fixed standard across all vehicles in the market regardless of their variable impacts. Nevertheless, regulations are a method for reducing environmental impacts which many governments have found to be useful. The EPA has imposed emissions standards on heavy-duty trucks, railroads, marine vessels, aircraft and auxiliary equipment.[9] These standards are becoming increasingly stringent for newer vehicles and are generally in units of mass per power-time. For example the most recent legislature in the U.S. requires that heavy-duty trucks emit less than 0.01 g/bhp-hr of PM, 0.20 g/bhp-hr of $NO_x$, and 0.14 g/bhp-hr of non-methane hyrdrocarbons.[10] As aforesaid, studies indicate that such standards have caused significant reductions in vehicle emissions factors in the past few decades.[11]

Similar standards have been imposed on the fuel composition, thus reducing emissions by affecting the pre-combustion phase. Since the 1990s legislation has been passed in the U.S. limiting the sulfur content in fuel. The most recent laws will cause most diesel used by trucks to contain less than 15 ppm of sulfur.[12] Benefits include increased potential for the use of catalyst-based emission control devices, such as diesel particulate filters and $NO_x$ adsorbers, and also the reduction of health impacts related to sulfur emissions.[13]

## 4.3. Changing Freight Sector Operations

Logistics operations can be adapted to reduce environmental externalities. Table 11 outlines the related options, which range from the application of technology by individual companies through public projects and legislation implemented by government. Some of these solutions are likely to be received with voluntary acceptance, since they can reduce fuel consumption and subsequently costs; however most are geared towards causing a

[9] [2] Ang-Olson and Ostria (2005)
[10] [11] DeiselNet.com (2006)
[11] [71] Yanowitz, McCormick and Graboski (2000)
[12] [11] DeiselNet.com (2006)
[13] [63] U.S. Environmental Protection Agency (2006)

reduction in vehicle-miles traveled to decrease pollutant emissions. As aforementioned, data indicate a strong trend in the growth of demand for freight transportation. As a result if operations are inhibited, the freight logistics sector and possibly the regional or national economy are likely to incur significant impacts.

#### 4.3.1. Enhancing Operations

As with the options directed at decreasing emissions by affecting emissions factors, technological innovation is expected to play a significant role in reducing vehicle-miles traveled. Technologies are a promising method for reducing emissions, since many of them also decrease costs to companies. Table 17 displays these options, which include technologies for enhanced vehicle routing, provision of real-time traffic information and facilitation of business to business (B2B) communication.

**Table 17 – Intelligent freight technologies.**
Source: [65] U.S. Federal Highway Administration (2005)

| | |
|---|---|
| **Asset Tracking** | • Tractor and Truck Tracking<br>• Chassis and Trailer Tracking<br>• Container Tracking<br>• Shipment/Cargo Tracking<br>• Route Adherence Monitoring |
| **On-Board Status Monitoring** | • Vehicle Operating Parameters<br>• Cargo and Freight Condition<br>• Intrusion and Tamper Detection<br>• Remote Locking and Unlocking<br>• Automated Hazmat Placarding<br>• Driver Emergency Call Buttons |
| **Gateway Facilitation** | • Driver Identification and Verification<br>• Non-Intrusive Inspections<br>• Compliance Facilitation<br>• Weigh-in-Motion<br>• Electronic Toll Payment |
| **Freight Status Information** | • Web-based Freight Portals<br>• Intermodal Data Exchange and Data<br>• Standards<br>• Web Services Software<br>• Standard Electronic Freight Information Transfer |
| **Network Status Information** | • Congestion Alerts and Avoidance<br>• Carrier Scheduling Support<br>• First Responder Support |

Among the options in Table 17, those related to routing considerations are becoming increasingly useful for logistics providers due to traffic congestion levels, especially in urban areas. Taniguchi and van der Heijden highlight three important benefits which are facilitated by technology and information, contributing to more efficient routing under congested conditions:[14]

[14] [53] Taniguchi and van der Heijden (2000)

1. To allow drivers and the control centre to communicate with each other.
2. To provide the real time information on the traffic conditions.
3. To store detailed historical pickup/delivery trucks operations data.

The first and second aspects contribute to avoidance of congested roadways by allowing dispatchers and drivers to make continual adaptations to routing and schedules. The third aspect has been studied to a lesser extent; however the researchers highlight the case of a Japanese milk-producing company which used historical data to develop more efficient distribution schemes. Such routing schemes can also be enhanced through the implementation of logistics optimization techniques, which have been studied in-depth as a tool for minimizing costs and travel times.[15] Such methods could be extended to include the objective of emissions reduction, likely through a reduction in vehicle-miles traveled and the time spent on heavily congested roadways.

E-commerce has impacted businesses, consumers and government by providing a means for rapid communication between geographically separated parties. B2B interaction in particular has attracted significant attention as impedance to the growing demand for freight transportation. For instance, in both Germany and Japan, cases are cited of competing companies combining efforts to allow a single carrier to transport their goods.[16] Such cooperation is particularly useful when goods must be shipped to a single location or a small area. Interaction allowing B2B coordination is much more viable as a result on online communication. Several web-based freight portals provide carriers and third-party logistics operators with online information regarding equipment reservations, rates, shipment status, and pick-up information.[17] In addition, third-party logistics services have been shown to cause significant reductions of environmental impacts.[18] Other studies also indicate that "logistical matching" systems could be very beneficial in terms of speed and costs, thus providing implementation incentive for shippers to contract with logistics providers via the internet.[19]

As shown in Figure 11, the load factor for freight vehicles in Europe tends to be less than 50%, indicating that many unnecessary trips are likely being made. Significant improvements can be made through efficient routing schemes such as in the case of Tesco, the largest supermarket chain in the U.K. which is estimated to have reduced fuel costs by £750,000 and $CO_2$ emissions by 23,000 tons over five years.[20] Such improvements could be further enhanced by the application of logistics systems analysis techniques applied for optimization with environmental considerations. These techniques include the aforestated routing methods and production and inventory management tools, which have been studied in detail in recent decades.[21] Vehicle design has also been shown to be a facet in which load factor improvements are possible. In one case, the compartmentalization of Safeway trucks in the U.K. allowed this company to make a

[15] [9] Daganzo (2005)
[16] [53] Taniguchi and van der Heijden (2000)
[17] [65] U.S. Federal Highway Administration (2005)
[18] [17] Facanha and Horvath (2005)
[19] [54] Taniguchi, Yamada and Naka (2002)
[20] [34] McKinnon (2003)
[21] [22] Graves, Rinnooy Kan and Zipkin (1993)

considerable decrease in the number of trips made and savings in costs.[22] Furthermore, the use of multiple deck levels in truck trailers has been cited as a method for significantly increasing vertical utilization.[23]

#### 4.3.2. Government Projects

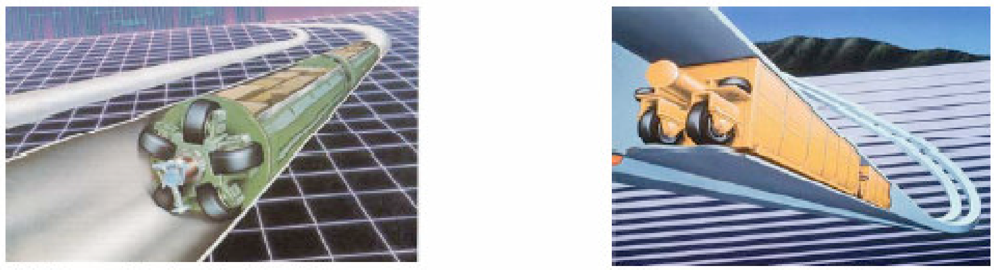
Transportation links and terminals are typically supported by government, making public funding and investment in such projects and important consideration. As shown in Section 3, studies of emissions factors and modal shares show that a shift away from trucking could greatly reduce pollutant emissions. Accordingly, governments and international organizations are increasingly promoting such a diversion. For instance underground transportation is being investigated as an option for American cities. In addition, the EC and TRB have encouraged the growth of rail and marine inland transport, along with enhanced interactivity between these two modes.

Underground freight transportation has been a feasible option for over a century. Around 100 years ago underground pneumatic capsule pipelines were used in U.S. cities to transport mail between central branches and local offices. Today many facilities use such systems including industrial plants and Disney World. A study conducted by the American Society of Civil Engineers yields very optimistic results regarding the use of freight pipelines in U.S. cities. The researchers point out that in many cases underground transportation of freight will be more cost-effective, environmentally friendly and energy efficient.[24] Another study has assessed the feasibility of installing a freight pipeline network in New York City, similar to a successful version which is already operating in Japan. The study examines six options for application, of which the first five are determined as both technically feasible and cost-effective:[25]

1. Conveyance of materials for underground tunnel construction
2 Conveyance of solid wastes to outside the city
3. Transportation of mail and parcels between NYC and Washington, D.C.
4. Transportation goods on pallets or in crates, boxes or bags
5. Transportation of containers between seaports and an inland processing/inspection station
6. Ferrying trucks to and from a large food market in Hunts Point of NYC

[22] [34] McKinnon (2003)
[23] [36] McKinnon and Campbell (1997)
[24] [4] ASCE Task Committee on Freight Pipelines and the Pipeline Division (1998)
[25] [29] Liu (2005)

**Figure 16 – Pneumatic capsule pipelines of circular and rectangular cross-section used in Japan.**
Source: Figure 1 in [29] Liu (2005)



(a) Round (circular) PCP (b) Rectangular PCP

Intermodal freight transportation is another commonly discussed term, which is used to describe the efficient utilization of rail, marine, and trucking modes in conjunction with one another. Accordingly, such multimodal networks require terminals which can function as transfer points. Seaports serve as important transshipment points that can influence inland networks. Thus to accommodate intermodal transport, ports should facilitate direct goods transfer between large ships to trains and to barges for locations which connect to inland waterways. However many ports, particularly in the U.S., do not facilitate intermodal activity, and require trucks for transport of goods to rail terminals. Adaptation of terminal locations would require enormous investment and seaport construction often requires significant dredging which can lead to ecosystem damage and destruction of wetlands, making the reconstruction of ports an unlikely option.[26] On the other hand, further development of the links between inland trade networks and seaports has been shown to be a feasible option. For example the Alameda Corridor has improved the link between the ports of Los Angeles and Long Beach to inland rail networks. Further investment in links to these ports has also been promoted as a means for increasing jobs, enhancing the economy and reducing environmental impacts.[27] Inland waterways are also important links for facilitating inland transport in the U.S. and Europe. Canals and inland ports are the economic backbone of many areas of the U.S. For example the Tulsa Port of Caloosa, Oklahoma has been described as the "proven economic engine for the region."[28] Inland terminals in Europe hold similar potential, as many are still being built and could be strategically placed to reduce trucking usage along with traffic congestion and environmental impacts.[29] Furthermore, freight villages are being constructed to increase intermodal freight activities. Such facilities could greatly enhance regional economies and decrease environmental impacts. The European Union defines a freight village as the following:[30]

> "A freight village is a defined area within which all activities relating to transport, logistics and the distribution of goods, both for national and international transit, are carried out by various operators. These operators

[26] [56] Transportation Research Board (1992)
[27] [37] Mecoy (2006)
[28] [43] Portiss (2002)
[29] [44] Priemus (2002)
[30] [12] European Commission (2000)

can either be owners or tenants of buildings and facilities (warehouses, break-bulk centres, storage areas, offices, car parks, etc.) which have been built there. Also in order to comply with free competition rules, a freight village must allow access to all companies involved in the activities set out above. A freight village must also be equipped with all the public facilities to carry out the above mentioned operations. If possible, it should also include public services for the staff and equipment of the users. In order to encourage intermodal transport for the handling of goods, a freight village must preferably be served by a multiplicity of transport modes (road, rail, deep sea, inland waterway, air). Finally, it is imperative that a freight village be run by a single body, either public or private."

In addition freight terminals can be utilized with a variety of other characteristics as shown in Table 18. The many possible aims and mechanisms for operation show the potential for terminal implementation in many different contexts.

**Table 18 – Classification of freight centers.**
Source: Table 3 in [68] Visser, Binsbergen and Nemoto (1999)

| | *Terminal development* | | | *Area development* | | | |
|---|---|---|---|---|---|---|---|
| | *Private terminal* | | *Public terminal* | *Transport oriented* | *Transport + other* | *Industrial + some transport* | *Port related* |
| | Forwarder DC | Transport company DC | Urban consolidation terminal | Freight Village | Industrial and logistic park | Business Grouping Developments | Special logistic area |
| *Transport modes* | Road-road Road-rail | Road-road Road-rail | Road-road | Road-road Road-rail-(barge) | Road-road Road-rail | Road-road | Road-sea/air Road-rail-sea/air |
| *Main aims* | Optimisation logistic operation | Optimisation transport operation | Traffic reduction in cities | Modal shift and urban traffic reduction | Regional economic growth and modal shift | Revitalising small- and medium-sized firms | Regional economic growth |
| *Operator (typically)* | Huge forwarder, retailer or transport company | Transport company | Transport company and an authority | Operating company (public influence) | local government and/or private company | Development by local government and transfer to private firms | Airport or harbour authorities |
| *Company structure* | Huge forwarder or retailer or company | Huge transport company or co-operating companies | Local transport company or co-operating companies | Mostly small companies | Large industrial companies and transport companies | Wholesalers and transport companies | International oriented companies |
| *Land use* | Small areas in urban areas or in the outskirts | Small areas in urban areas or in the outskirts | Small areas in urban areas or in the outskirts | Large areas in the outskirts of urban areas | Large areas in the outskirts or at old industrial areas | Large areas in the outskirts of urban area | Near airports and harbours |
| *Orienta-tion* | Urban area | Urban area | Urban area | Urban and regional | Regional and international | Urban area and Regional | International |

As with any large public project, considerable planning is a necessity. As a result an analytical framework accounting for both environmental and economic effects should be applied. One example of such an analysis is a multi-objective programming formulation which has been applied for a terminal location problem in Japan.[31] The three objectives are to minimize travel cost, travel time and $CO_2$ emissions. Furthermore facility location problems have been analyzed in detail through the field of operations research, primarily with respect to costs, but also for reliability and time savings.[32] Therefore these

[31] [70] Yamada, Taniguchi and Noritake (1999)
[32] [10] Daskin (1995)

techniques could be applied within a framework based on the environment and economics.

Another significant concern is delay and subsequently idling in the vicinity of terminals, which is caused by vehicle flows in excess of capacity. For example, slow customs clearance in the NAFTA trade corridor has been cited as the primary cause of idling at North American borders.[33] One option for reducing terminal queues is the implementation of internet port information systems, which allow terminal operators to make congestion information available to freight carriers. Such a mechanism has been implemented in both Vancouver and New York with varying success.[34]

Infrastructure for links, as mentioned in Section 3, is another important aspect which is dependent on government funding. In addition to having the aforementioned supply-chain impacts on the environment, pavement characteristics have been cited as a contributing factor to truck emissions. Harder and smoother pavements tend to cause less rolling resistance, thus decreasing fuel consumption and emissions factors. In cold climates, trucks traveling on concrete and asphalt have been shown to have similar emissions; however in warmer conditions, truck emissions occurring as a result of travel on concrete pavement have been measured to reduce fuel consumption by up to 8% versus asphalt.[35] Accordingly truck routes could be diverted onto pavements which have less rolling resistance or transportation agencies could revise pavement their standards to mitigate emissions problems. However, adaptations made with regards to pavement quality may have significant economic effects, either for freight sector operations or government expenditure.

#### 4.3.3. Government Policies

As with emissions control technologies, logistics companies may typically have little economic incentive to adapt their operations and routing, or to make modal shifts. As a result government policies must be implemented to influence behavior. From the perspective of economic theory, policy options affecting freight carriers can be categorized by regulation, taxation and market creation.

A relatively new regulation method is load factor requirements. For example, in Copenhagen drivers can only obtain access to loading/unloading zones in the inner city if their vehicle load factor is greater than 60% and vehicle age is less than 8 years.[36] This program is expected to reduce both vehicle-miles traveled and traffic congestion. Other cities have also employed regulations by designating restriction zones, typically prohibiting truck travel in congested downtown areas or requiring freight vehicles to use specific trunk roads. Zonal policies have been implemented in the U.K., Belgium and Sweden.[37] Analogous to the spatial restrictions on vehicle movement, timing regulations can also be applied. Such regulations are employed to reduce the number of freight

[33] [1] Ang-Olson and Cowart (2002)
[34] [21] Geroliminis and Daganzo (2005)
[35] [55] Taylor (2001)
[36] [27] Kjaersgaard and Jensen (2004)
[37] [21] Geroliminis and Daganzo (2005)

vehicles entering congested areas during peak hours. Night delivery schemes have already been implemented in many cities including Paris, London and Rome.[38] These types of restrictions can reduce external costs by diverting emissions to less populated areas and relieving urban congestion. Another consideration is vehicle weight limitations. The average density of transported goods has decreased in recent decades as a result of more technology-oriented consumption. Subsequently, truck capacity is often a function of weight rather than volume; therefore an increase in weight limitations could potentially facilitate greater vehicle utilization, and decrease emissions factors.[39] However it has been noted that the impact of weight limit changes will have many effects on subsequent emissions levels and the outcome is not entirely predictable. Such effects include the increased emissions per mile-traveled by vehicles laden with greater weight, and the potential demand shift for trucking which will be affected by the tradeoff between costs versus increased capacity. Furthermore the shift in acceleration and cruising speeds will affect traffic flow in general, resulting in unique effects on emissions for particular settings.[40]

Various forms of taxation policies have been used in attempts to force companies to pay a price nearer the marginal social cost. Ruesch has reviewed such pricing schemes that have been introduced in countries such as U.K., Norway, Italy, Switzerland and Austria.[41] In London all vehicles including those carrying freight are charged 5 pounds for entering the city during weekdays. In addition, the government studies have been conducted to investigate the nation-wide Lorry Road User Charge which may be implemented in within the next few years.[42] In Switzerland, long-distance trucking taxes are levied based on distance traveled, vehicle weight and the emissions category of the vehicle.[43] One additional possibility is fuel tax shifting, which is however likely to attract significant opposition from industry.

Emissions trading markets are another policy option which could be applied to the freight sector. As a result emissions as a whole would be reduced for the region in which the market is enforced. Hypothetically, such a system might be implemented by capping total emissions and then either auctioning or assigning tradable pollution rights to companies. In the first case, the profits would go to the government, whereas in the second, they are taken by companies. However emissions can be difficult to measure due to the large number and wide variety of vehicles used by freight carriers today, and the relative freedom of travel that roadways provide. Other possibilities could be a cap and trade system for ton-miles traveled or total vehicle-miles. Economists tend to encourage such market oriented approaches, since it allows companies to induce an efficient equilibrium. In the U.S., trading has been applied with some success to sulfur dioxide emissions from the electric utilities industry.[44] Additionally, trading schemes are being

[38] [21] Geroliminis and Daganzo (2005)
[39] [35] McKinnon (2005)
[40] [58] Transportation Research Board (2002)
[41] [47] Ruesch (2004)
[42] [59] U.K. Department of Transport (2005)
[43] [51] Suter and Walter (2001)
[44] [46] Rosen (2002)

investigated for European aviation, which could potentially have some similarities to those for freight.[45]

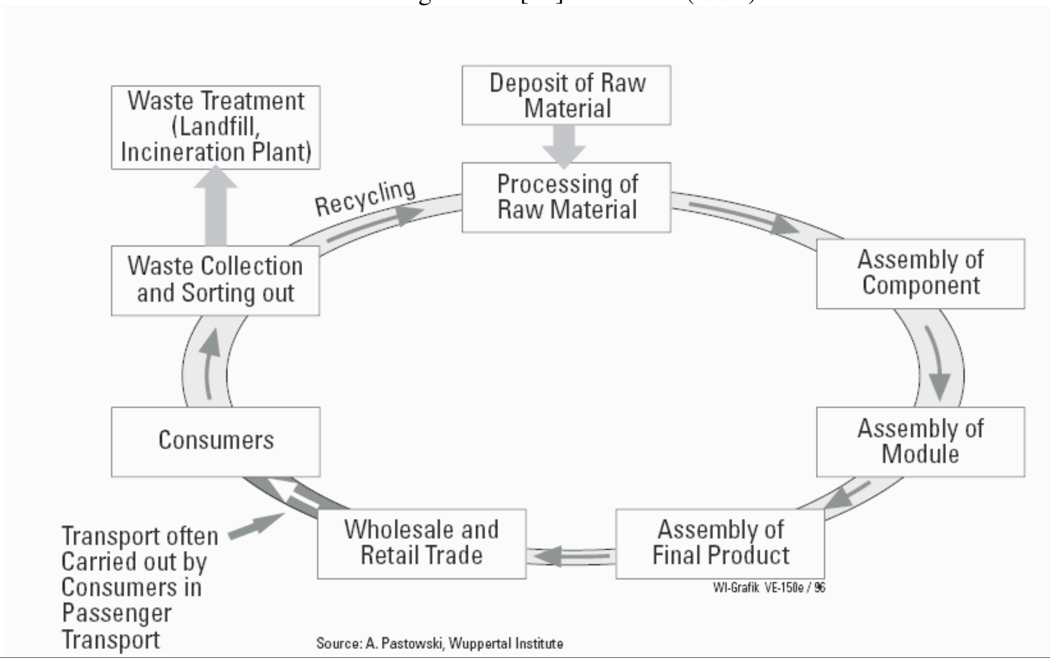
### 4.4. Considering Demand and Economic Development

The options discussed thus far have focused primarily on transportation considerations; however if reductions in environmental externalities from these options are not satisfactory, analysis must be extended beyond Green Logistics to a broader framework. Related options would likely be directed at curbing freight transport demand growth with consideration for geographical and commodity characteristics within the context of the economy and society. However, as shown in Figure 10 the growth in freight transport volume tends to be highly correlated with that of GDP. Thus, these options could hinder economic development; rendering them as generally less desirable.

Geographical characteristics of the economy and society have significant effects on the demand for freight transport. McKinnon highlights several studies which relate to the "pattern of regional" sourcing.[46] This concept describes the geographical distribution of various players in production supply-chains, and the potential for transport demand reduction by vertical integration of regional supply structures. A variety of geographical improvements could be made throughout the life-cycle of a good, as illustrated by Figure 17, which displays the many steps at which freight transport in often required. Analysis at this broad level could be greatly enhanced by tools for analyzing logistics through commodities rather than vehicles. Such methods have been developed by Vanek and Morlok, who predict significant energy savings through their implementation.

[45] [25] International Air Transport Association (2001)
[46] [34] McKinnon (2003)

**Figure 17 – The role of freight transport in the economic process.**
Source: Figure 7 in [42] Pastowski (1997)




Researchers have also assessed some of the economic and cultural characteristics of societies which induce demand for freight movement. Pastowski lists options for reducing demand which include the following:[47]

1. Increasing the intensity of utilization of products
2. Increasing the durability of products
3. Reducing the material requirements of a product
4. Designing products to enhance remanufacturing and recycling

Acceptance of such transformations requires changes in production practices, which are necessitated by shifts in consumer preferences. Accordingly, the dematerialization of economies is requisite for reducing demand for freight transport. Dematerialization is generally defined as the reduction in the resource demand per unit of GDP. Several comparative studies of national economies have shown that dematerialization is often linked to modernization.[48] Therefore such a process parallels the concept of the environmental Kuznets curve, as attitudes shift towards a post-material lifestyle, in which general quality of life aspects supersede material considerations. Such attitude shifts may serve as the most useful mechanisms for causing industry to reduce environmental impacts.

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[47] [42] Pastowski (1997)
[48] [48] Schleicher-Tappeser, Hey and Steen (1998)

## 5. Conclusion

Determination of the most progressive options for shifting the freight logistics industry towards more sustainable goals will require careful planning and coordination between multiple parties. Both consumers and government will play roles in influencing industry to consider implementation of solutions which will reduce environmental impacts. The influence of consumers can play a significant role in determining the demand for goods, since they have the potential to incentivize the voluntarily implementation of Green Logistics schemes. Such behaviors should be analyzed from both an economic and sociological viewpoint to determine their potential effects on logistics systems. In addition, government can guide the logistics industry with policies which will induce sustainable practices. Current regulations and policies applied to other industries can provide a menu of feasible options. Within this framework, various tools for analysis, including those of logistics systems analysis and supply chain management, should be applied towards analyzing the effects of policy options on industry. An interdisciplinary analysis would allow for the concepts of a variety of fields to be incorporated, including transportation engineering, economics, environmental science, operations research and urban planning. As a result the feasibility and practicality of various policy options can be assessed to distinguish their suitability for specific contexts.

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