Potential for Meeting the EU New Passenger Car CO_2 Emissions Targets

by

Kandarp Bhatt

Bachelor of Technology (Honours) in Ocean Engineering & Naval Architecture
Indian Institute of Technology, Kharagpur, 1999

Submitted to the System Design and Management Program
in partial fulfillment of the requirements for the degree of

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at the

Massachusetts Institute of Technology

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[February 2011]

Signature of author: ______________________
Engineering Systems Division
System Design and Management Program

Certified by: ______________________
John B. Heywood
Professor of Mechanical Engineering
Sun Jae Professor, Emeritus
Thesis Supervisor

Accepted by: ______________________
Pat Hale
Director
System Design and Management Program

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Abstract

In 2009, the European Parliament agreed to limit the CO_2 emissions from new passenger cars sold in the European Union to an average of 130g/km by 2015. Further, a probable longer-term CO_2 emissions target of 95g/km is specified for 2020. This thesis attempts to assess the feasibility of meeting these targets in a representative European Union by developing and evaluating Optimistic and Realistic scenarios of varied powertrain sales mix, vehicle weight reduction levels, and Emphasis on Reduction of Fuel Consumption (ERFC) using a European New Passenger Cars CO_2 Emissions Model. Further, this thesis develops custom fleet models for select member states to understand the impact of the developed scenarios on reduction of fuel use and on the diesel to gasoline fuel use ratio. The thesis finds that while the European Union is poised to meet the 2015 target in an Optimistic scenario, it will find it difficult to do so in a Realistic scenario. Moreover, the 2020 target would not be achieved in either of the two scenarios. Further, the diesel to gasoline fuel use ratio will continue to rise through year 2020 for the studied countries, potentially reaching as high as 3 in the case of France and at least as high as 0.71 in the case of Germany. Finally, an increase in ERFC and introduction of PHEVs would most help reduce fuel use in all studied countries. In France and Italy, a reduction of Diesel car sales would additionally be significantly useful in reducing the fuel use. Whereas, in Germany and UK, a higher number of Turbocharged Gasoline cars would be another significant option to reduce fuel use.

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1. Introduction

1.1 The European Parliament Regulation For Setting Emissions Standards of New Passenger Cars

On April 23, 2009, the European Parliament passed a regulation (Regulation) to set emission performance standards for new passenger cars registered in the European Community [European Commission 2010]. This measure came as a part of the Community's approach to reduce CO_2 emissions from light-duty vehicles.

Some salient elements of the Regulation include the following:

- 2015 onwards, the average CO_2 emissions from 100% of each manufacturer's newly registered passenger cars should be 130 grams per kilometre (g/km) or less.
- Heavier cars would be allowed to emit more than the lighter cars, however the overall new car fleet average would be preserved at or below 130g CO_2/km.
- From 2012 until 2018, the manufacturers falling behind the specified average emissions target will be assessed a lower fine for smaller excess emissions. For example, €5/per car for first gram of excess emissions per kilometre, €15 for second gram, €25 for third gram and €95 for all subsequent grams of excess emissions per kilometre. However, 2019 onwards, the fine for the first gram of excess CO_2 emissions per kilometre would already be €95.
- The EU member states would monitor the regulation compliance on the basis of certificate of conformity issued by car manufacturers and report the same to the European Commission.
- A longer-term target of 95g CO_2/km average emissions is specified for the new passenger car fleet beginning in year 2020. The details about the modalities of achieving this target and the aspects of its implementation will be worked out after a review no later than the beginning of 2013.

The regulation observes that its aim is to incentivize investment in new technologies by the car industry with the belief that such new technologies would lead to significantly lower emissions than from traditional technology cars.

1.2 The Context of the Regulation

1.2.1 European Union's Commitment to Tackle Global Warming

The European Union (EU) has acknowledged the phenomenon of Global Warming[1] since 1993, when it approved the conclusion of the United Nations Framework Convention on Climate Change [European Commission 2007]. The Convention required the member parties to formulate and implement climate change mitigation programs at national and regional level, as appropriate. The Convention was followed by the Kyoto Protocol in 1997, which the EU approved in 2002 [European Council 2002]. The Kyoto Protocol required the EU member states to collectively reduce their greenhouse gas emissions by 8% below 1990 levels between 2008 and 2012.

In parallel to the aforementioned climate change discourse, the EU has been working on an agenda of making its economy one of the most competitive in the world and achieving sustainable economic growth. The Lisbon Strategy of 2000 was a key instrument in this regard that was based on economic, social and environmental pillars [Lisbon Strategy 2000]. The EU hopes that by leading the formulation and implementation of stricter climate change mitigation measures it will be able to encourage the development and application of new environmental technologies. This would promote innovation that should propel EU to become a leader in clean and fuel efficient technologies. In turn, such leadership should lead to greater exports to emerging markets in the short term, and in the long-term it

[1] A detailed discussion of Global Warming and related concepts is beyond the scope of this document. Reader may find an excellent discussion of the same in IPCC 2007, as in several other academic papers concerning the topic.

should provide a competitive edge to the EU economy [European Commission 2007b].

In 2007, therefore, the European Commission (EC) proposed, and the Council and European Parliament endorsed, that the EU pursues the objective of a 30% reduction in greenhouse gas emissions below the 1990 levels by the developed countries by 2020 in international negotiations for a successor to the Kyoto Protocol. Further, until an international agreement was reached, the EU agreed to independently commit itself to achieving a 20% reduction below the 1990 levels in greenhouse gas emissions by 2020 [European Commission 2007a].

1.2.2 The Emphasis on Passenger Cars

As of 2007, Transport was the second largest greenhouse gas emitting sector in EU-27 (Fig. 1.1).

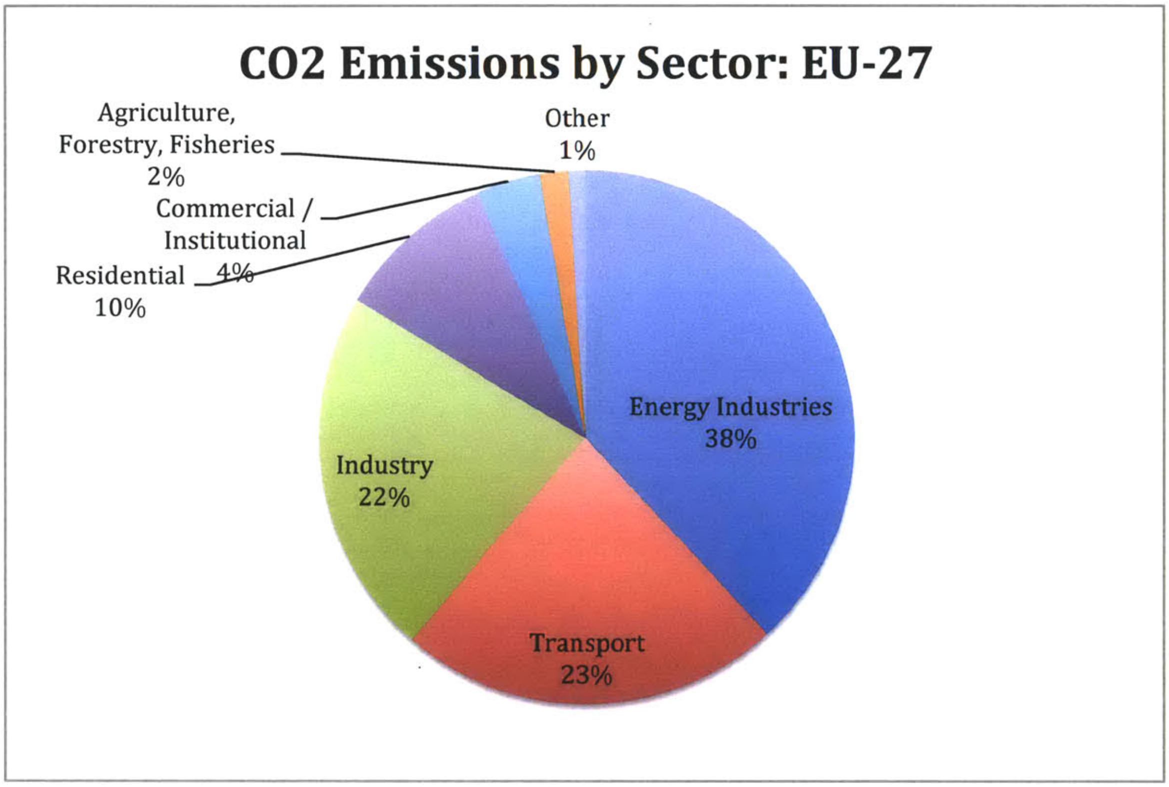

Fig. 1.1 CO_2 Emissions by Sector: EU-27 (Shares of Total CO_2 Emissions: 2007) Source: European Commission, 2010a

Given the EU's commitment to reducing greenhouse gas emissions, it was accepted and considered fair that all economic sectors must contribute to the reduction effort [European Commission 2007c]. However, while all other sectors had reduced greenhouse gas emissions between 1990 and 2007, Transport sector had increased emissions by 26% (Fig. 1.2).

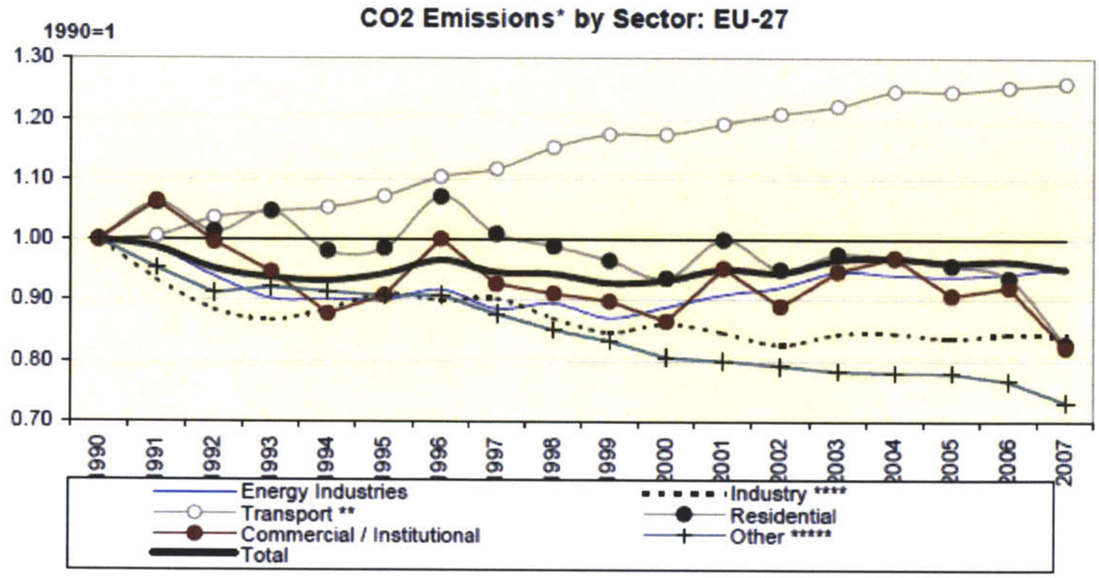

Fig 1.2 CO2 Emissions by Sector: EU-27. Source: European Commission, 2010a

Of all the modes of transport, Road Transport was the biggest emission source accounting for roughly 71% of all transport related emissions (Fig. 1.3), with passenger cars[2] accounting for 2/3 of all road transport emissions [European Commission 2007d].

[2] Passenger Cars are the so-called category M1 vehicles. The Regulation exempts special-purpose vehicles (Motor Caravans, Armoured Vehicles, those accommodating wheelchair use, etc.) from its CO_2 emissions consideration.

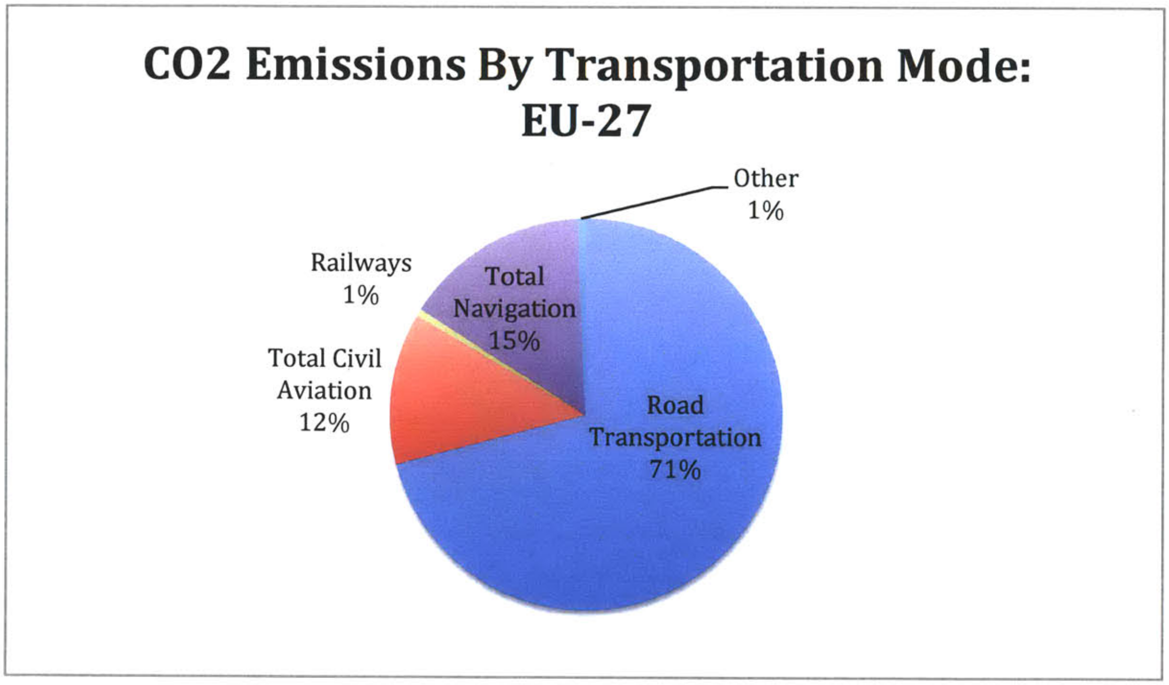

Fig. 1.3 Share by Mode in Total Transport CO_2 Emissions, Including International Bunkers: EU-27 (2007). Source: European Commission, 2010b

All in all, passenger cars account for roughly 12% of overall EU CO_2 emissions [European Commission, 2007]. Hence, it can be seen that passenger cars are a significant source of greenhouse gas emissions in the EU, and as such they become an important component in the overall EU emissions reduction strategy.

1.3 The Evolution of the Regulation

In order to reduce the CO_2 emissions from passenger cars, in 1995 the EC adopted a Community Strategy [European Commission 2007] that was based on three points:

a. Voluntary reduction commitment by car manufacturers
b. Improvement in consumer information, and
c. Fiscal measures to promote fuel efficient vehicles

In 1998, the European Automobile Manufacturers Association (ACEA) committed to reducing the average CO_2 emissions from their new passenger cars fleet to 140 g CO_2/km by 2008. The Japanese (JAMA) and Korean (KAMA) Automobile Manufacturers Associations committed in 1999 to reduce the average CO_2 emissions from their new passenger cars fleet to 140 g CO_2/km by 2009. Figure 1.4 shows the performance of some manufacturers by 2005 on the voluntary reduction commitment.

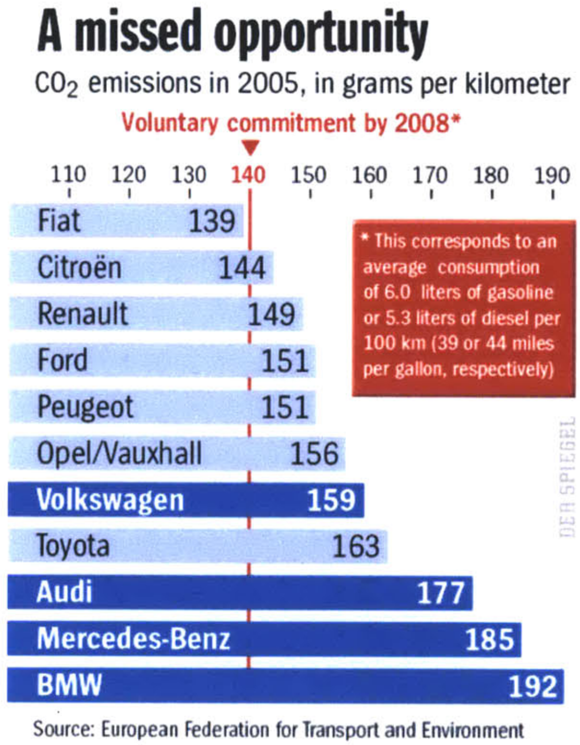

Fig. 1.4 Car Manufacturers' 2005 CO2 Emissions Against Voluntarily Committed Level By 2008. Source: Spiegel, 2007

Upon reviewing the Community Strategy in 2007, the EC determined that if there were no change in policy by way of additional measures, the EU objective of 120[3] g CO_2/km by 2012 would not be met. After evaluating various options, a need for a regulation was identified to meet the emissions reduction objective [European Commission 2007c] paving the way for the introduction of the Regulation in April 2009. Figure 1.5 summarizes the evolution of the regulation.

[3] While improvements in vehicle technology were expected to reduce average emissions to no more than 130g CO_2/km, complementary measures were supposed to bring about an additional 10g CO_2/km emissions reduction. The overall emissions would therefore be reduced to 120g CO_2/km.

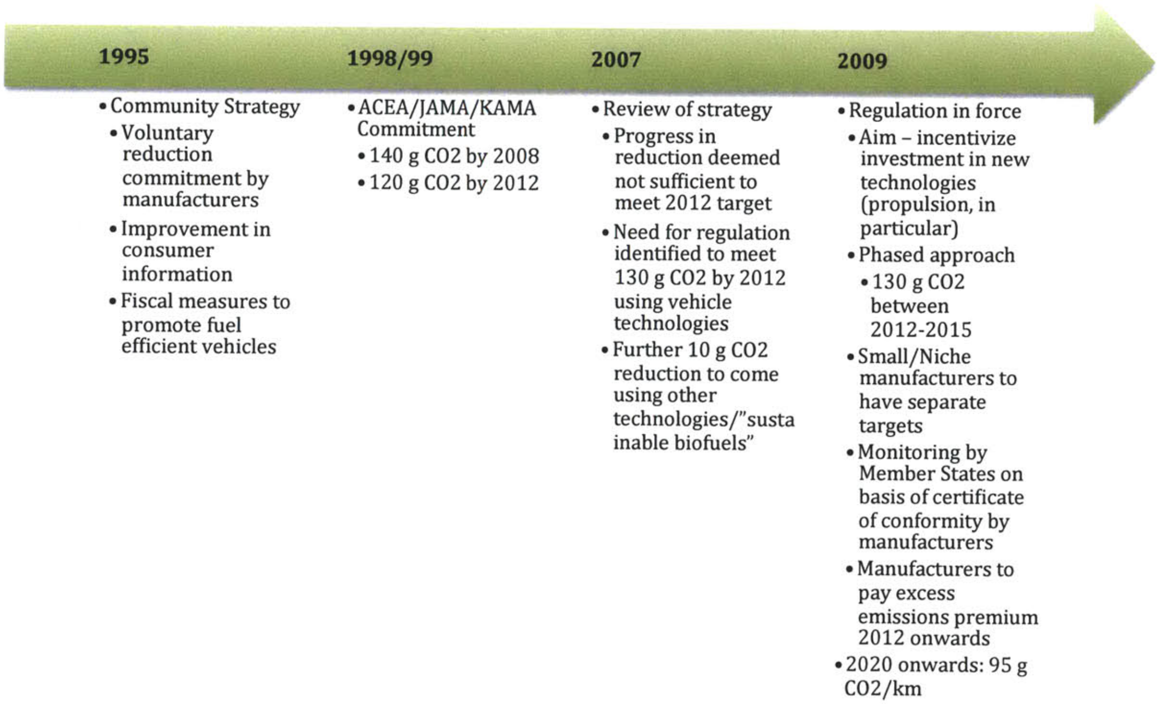

Fig. 1.5 The Evolution of EU Passenger Car Emissions Regulation

1.4 Purpose and Overview

The purpose of this research is to develop various sales mix scenarios for select EU member states in 2015 and 2020 in order to assess the feasibility of meeting the mandated CO_2 emissions targets for both the years, to understand the impact of the scenarios on the diesel to gasoline fuel use ratio, and the fuel use reduction potential for specific countries using customized fleet models. The aim of this analysis is not to predict the future emissions levels in the EU. Rather, it attempts to understand the impact of different possible eventualities that include variations in new technology (Battery Electric Vehicles, Plug-in Hybrid Vehicles, Gasoline/Diesel

Hybrids, etc.) penetration, vehicle weight reduction opportunities and fuel consumption reduction versus increased performance tradeoff.

2. The European Passenger Cars CO_2 Emissions Model

2.1 A Representative European Union

Since this research does not intend to predict the future sales mix and instead focuses on understanding the broader impact of certain possible scenarios, it was decided to select a limited number of member states of the EU for analysis as opposed to examining all member states. The selection of the member states was carried out under the guiding principle of attempting to create a representative EU. With this objective in mind, the EU-27 countries were compared on the basis of three parameters:

- Motorization,
- Gross Domestic Product (GDP), and
- Population

The analysis of International Monetary Fund's (IMF) [IMF 2009] and ACEA's [ACEA 2009] data yielded the following average values of these parameters for EU-27:

- Average Motorization – 426 cars per thousand people
- Average GDP - $36,000 per capita, and
- Average Nation's Population – 18 million

This led to a simple (but sufficient for the purposes of this research) classification of EU-27 countries in three groups, namely:

2.1.1 Large, Higher-Than-Average GDP/Capita, Highly Motorized Countries

This group comprised of countries whose GDP, Population and Motorization were higher than the average GDP, Population and Motorization of EU-27 countries. These countries were France, Germany, Italy and the United Kingdom. Since this was a small group and all countries were significant to a representative Europe, all four were selected for this research. Figure 2.1 illustrates this group of countries and the relevant criteria.

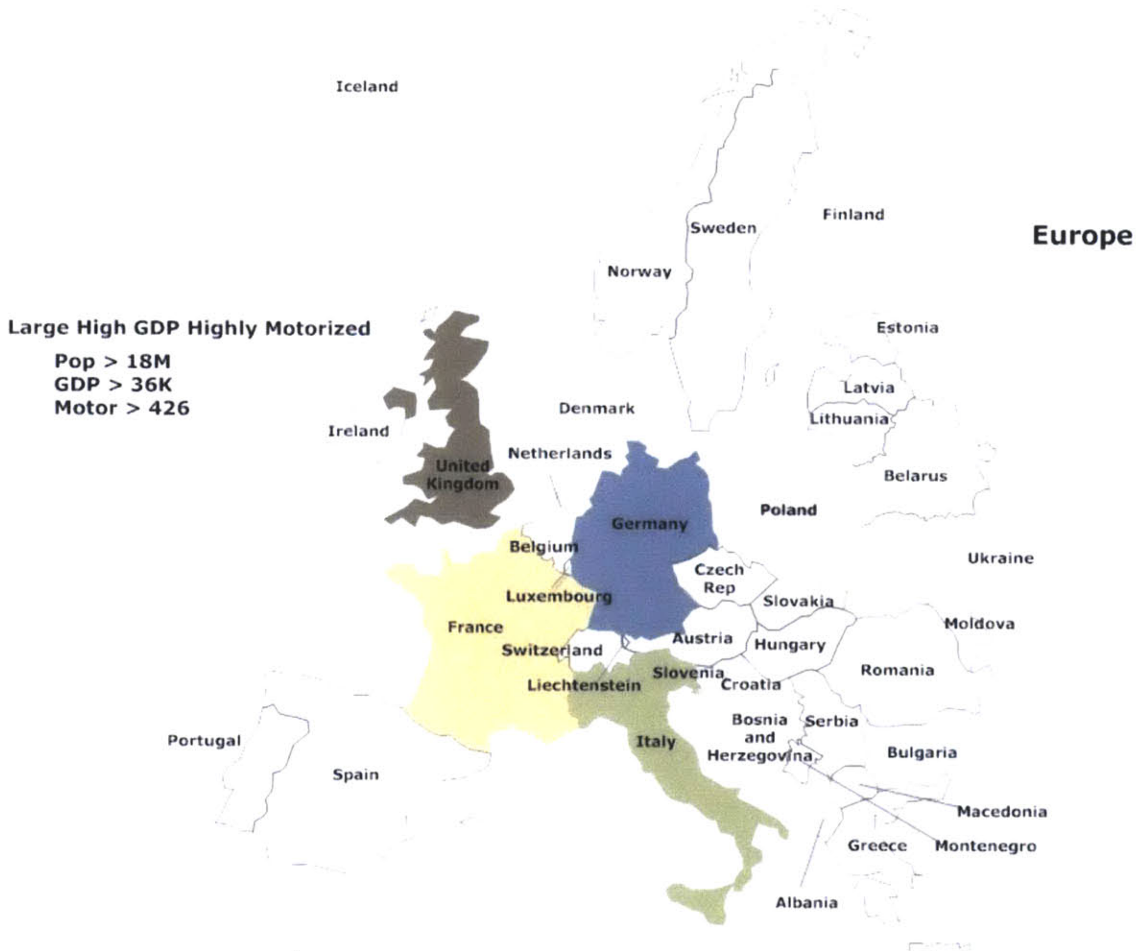

Fig. 2.1 A Representative European Union: Large, Higher-Than-Average GDP/Capita, Highly Motorized Countries

Table 2.1 lists the countries in this group and their respective GDP, Population and Motorization data.

Country	GDP per capita ($)	Population (Millions)	Motorization (cars/1000 inhabitants in year 2006)
Germany	44,660.41	82.12	566
France	46,015.92	62.277	504
UK	43,785.34	61.073	471
Italy	38,996.17	59.336	597

Table 2.1 The Large, Higher-Than-Average GDP/Capita, Highly Motorized Countries

2.1.2 Small, Lower-Than-Average GDP/Capita, Lowly Motorized Countries

This group comprised of countries whose GDP, Population and Motorization were lower than the average GDP, Population and Motorization of EU-27 countries. These countries included the Czech Republic, Portugal, Slovakia, Hungary, Romania, Bulgaria, Latvia, Estonia and Malta. Figure 2.2 illustrates this group of countries.

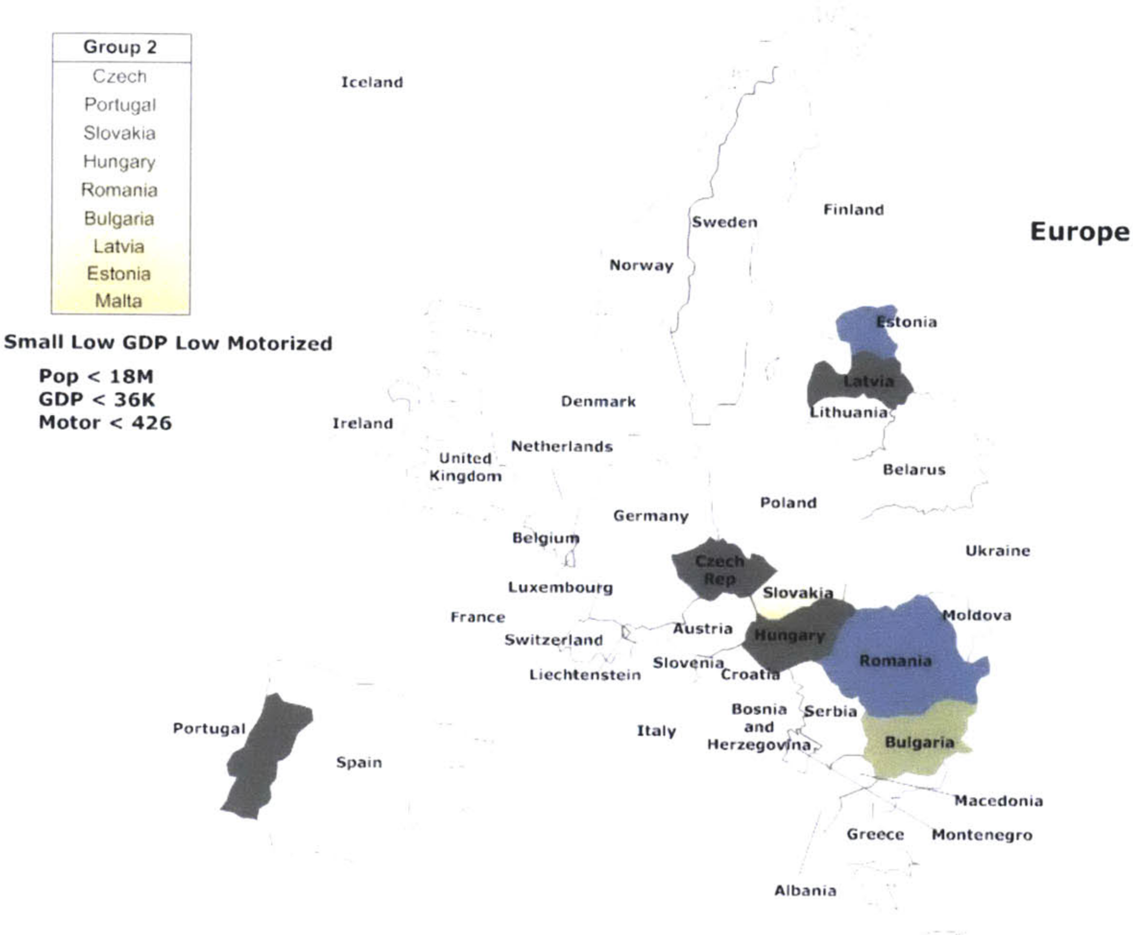

Fig 2.2 Small, Lower-Than-Average GDP/Capita, Lowly Motorized European Countries

For the purpose of this research, the Czech Republic, Portugal and Hungary were selected on the basis of availability of new passenger car sales data and their relative size as compared with the other countries in the group. Figure 2.3 illustrates these selected countries and the relevant criteria.

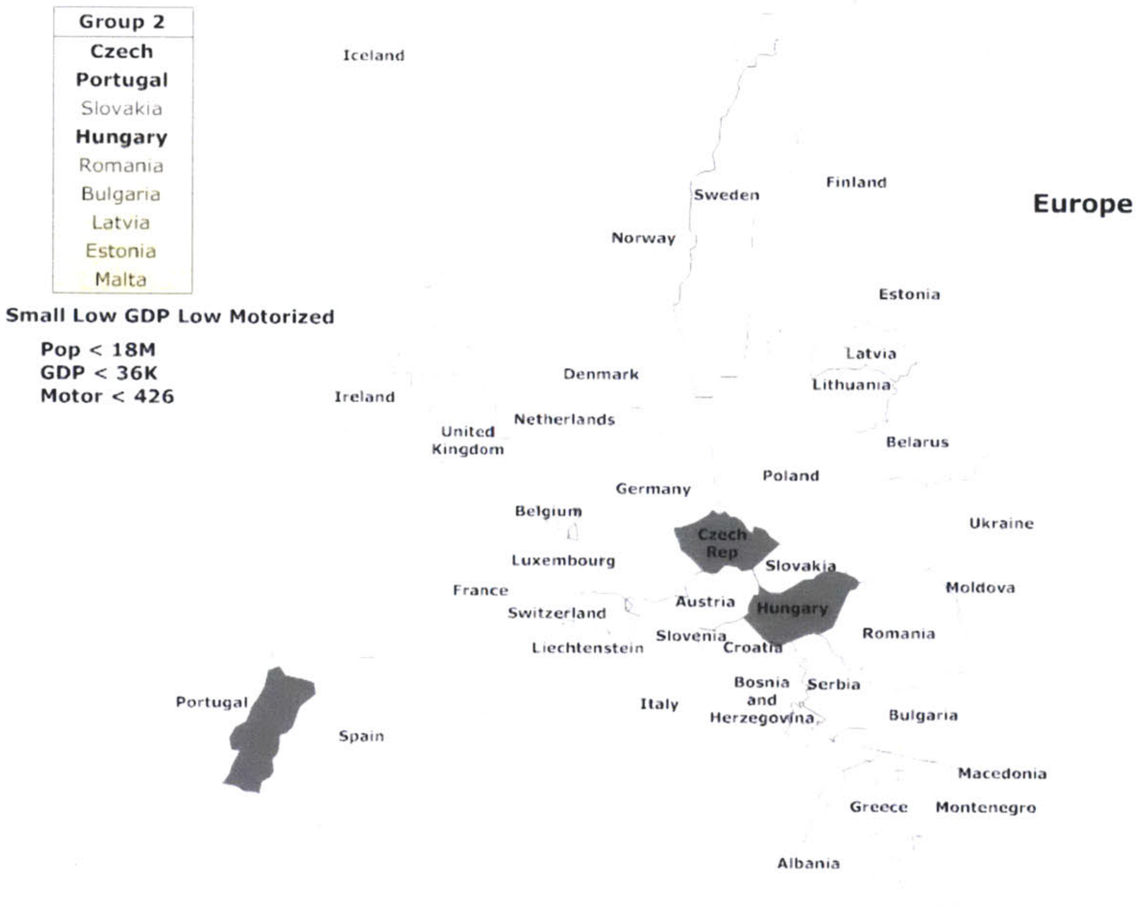

Fig 2.3 A Representative European Union: Small, Lower-Than-Average GDP/Capita, Lowly Motorized Countries

Table 2.2 lists all the EU countries in this group and their respective GDP, Population and Motorization data.

Country	GDP per capita ($)	Population (Millions)	Motorization (cars/1000 inhabitants in year 2006)
Romania	9,291.70	21.489	167
Portugal	22,997.41	10.631	405
Czech Republic	21,027.48	10.323	399
Hungary	15,542.27	10.055	293
Bulgaria	6,856.91	7.582	230
Slovakia	17,630.12	5.411	247
Latvia	14,997.27	2.271	360
Estonia	17,299.05	1.343	413
Malta	20,202.28	0.413	NA

Tables 2.2 Small, Lower-Than-Average GDP/Capita, Lowly Motorized Countries

2.1.3 Eclectic Mix Middle Layer Countries

This group comprised of countries, which did not fall into either of the above classifications. These countries have GDP, Population and Motorization figures such that they cannot be easily characterized. These countries included Spain, Poland, Netherlands, Belgium, Luxembourg, Ireland, Denmark, Sweden, Finland, Lithuania, Austria, Slovenia, Greece and Cyprus. Figure 2.4 illustrates this group of countries.

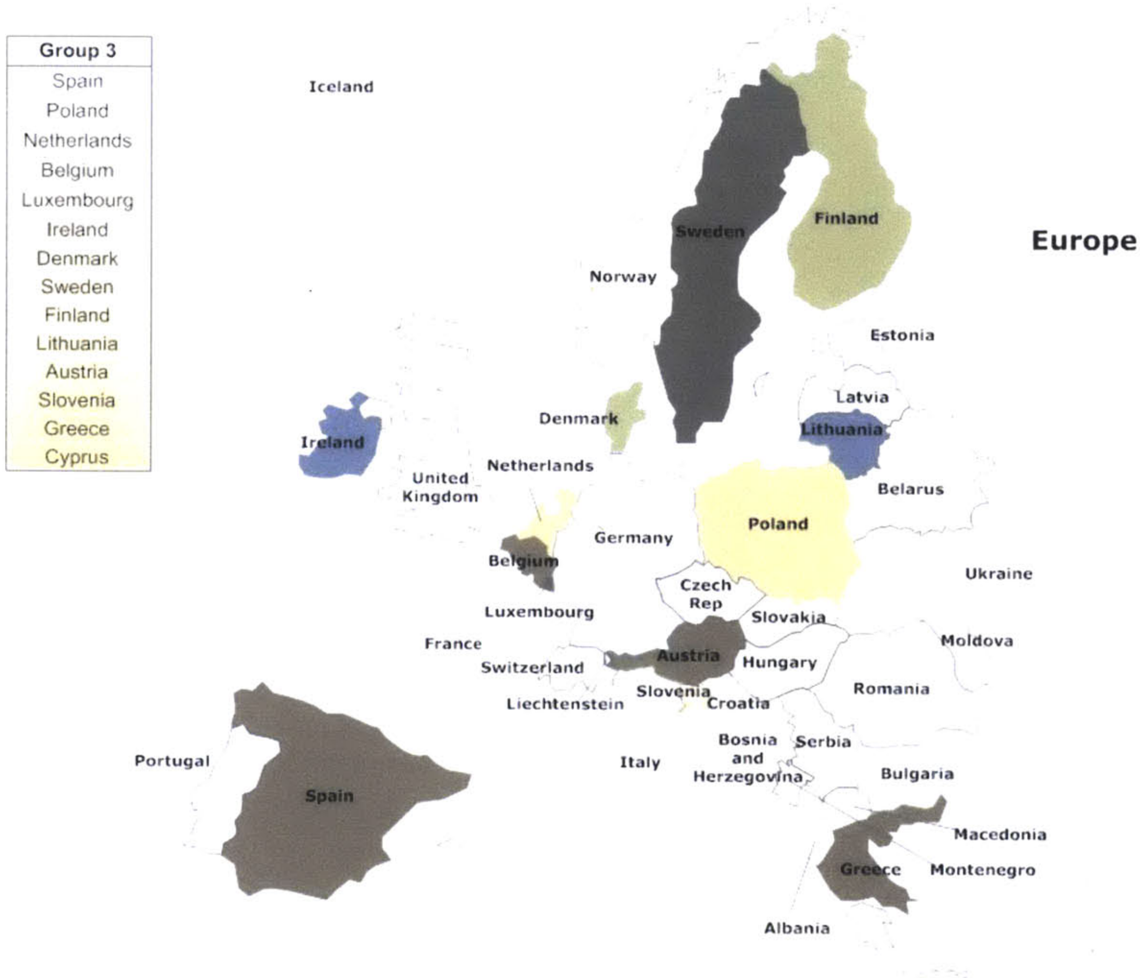

Fig. 2.4 Eclectic Mix Middle Layer Countries

For the purpose of this research, Spain and Netherlands were chosen on the basis of availability of new passenger car sales data and their relative size as compared with the other countries in the group.

Table 2.3 lists all the EU countries in this group and their respective GDP, Population and Motorization data.

Country	GDP per capita ($)	Population (Millions)	Motorization (cars/1000 inhabitants in year 2006)
Spain	35,331.49	45.618	464
Poland	13,798.88	38.1	351
Netherlands	52,019.03	16.704	442
Greece	32,004.61	11.172	NA
Belgium	47,107.83	10.75	470
Sweden	52,789.61	9.179	461
Austria	50,098.43	8.29	507
Denmark	62,625.57	5.476	371
Finland	51,989.38	5.27	478
Ireland	61,809.61	4.422	418
Lithuania	14,085.86	3.358	470
Slovenia	27,148.64	2.013	488
Cyprus	32,772.07	0.761	NA
Luxembourg	113,043.98	0.486	661

Table 2.3 Eclectic Mix Middle Layer Countries

2.1.4 Aggregate EU Representation

The representative European Union, for the purpose of this research, therefore comprises of nine countries (Fig. 2.5): Czech Republic, France, Germany, Hungary, Italy, Netherlands, Portugal, Spain, and the United Kingdom. Collectively, these countries represent 72% of the population and 86% of the new passenger car sales of the EU-27 countries.

Fig. 2.5 A Representative European Union

2.2 Timeframes Analyzed

There were two timeframes of importance to this research:

- Short-term mandate timeframe – Today to year 2015, when the target of average emissions of 130 g CO_2/km is supposed to be met (on-average) by 100% of all manufacturers' new passenger cars sold in the EU.
- Medium-term mandate timeframe – Today to year 2020, when the target of average emissions of 95 g CO_2/km is supposed to be met by new passenger cars sold in the EU.

In the context of this research, Today is defined as the beginning of 2010. Similarly, year 2015 and 2020 refer to the first calendar days of the respective years, in accordance with the convention of the Regulation.

2.3 Methodology

The methodology of analysis followed for this research builds upon the basic framework described in Heywood (2010). In addition, the process that this research follows draws from and builds upon those adopted in Bodek and Heywood (2008) and Cheah, et al (2007). Figure 2.6 gives an overview of the analysis framework and its principal components.

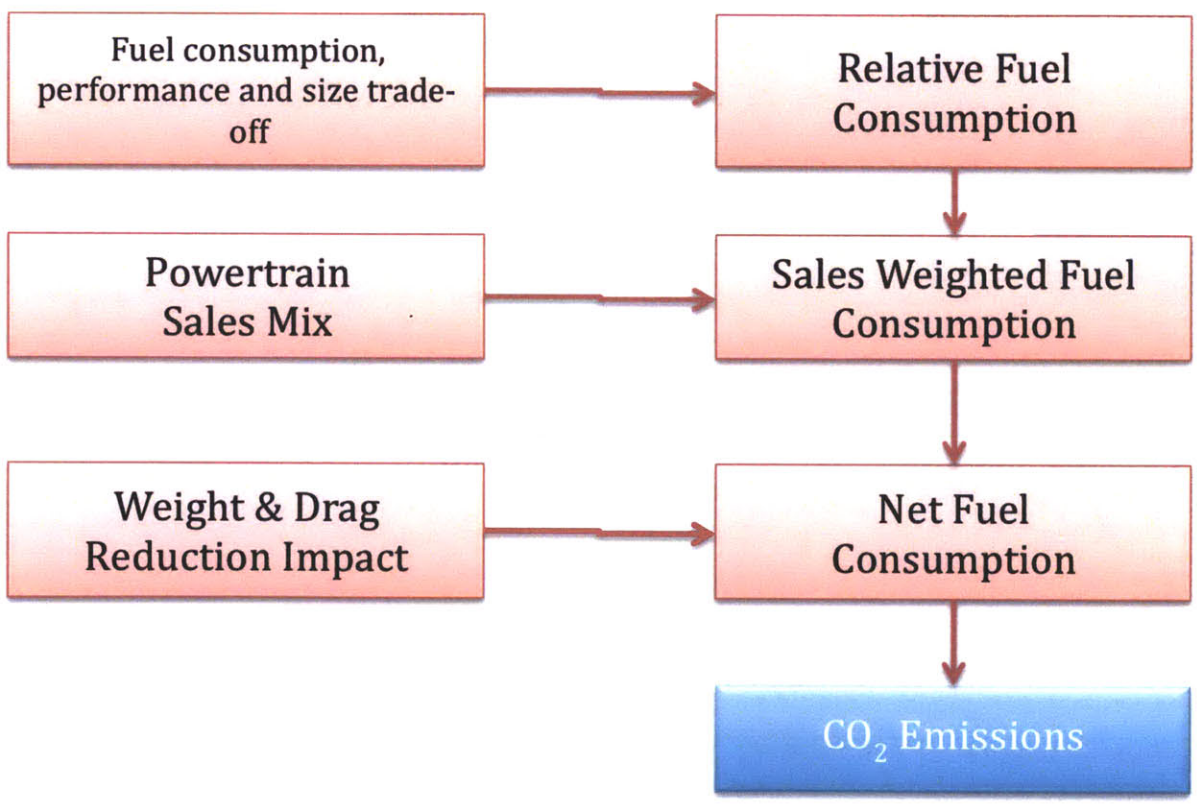

Fig. 2.6 New Passenger Cars CO_2 Emissions Computation Model Overview

Let us look at the individual components in more details.

2.3.1 Fuel Consumption, Performance and Size Trade-off

A reduction in Fuel Consumption (FC) due to improvements in engine and vehicle technology is often offset by the negative impact of increasing vehicle size, weight and power. The concept of Emphasis on Reducing Fuel Consumption (ERFC) helps us compare the realized FC reduction with the FC reduction possible with constant performance and size [Heywood, 2010].

$$\text{ERFC} = \frac{\text{FC Reduction Realized on Road}}{\text{FC Reduction Possible with Constant Performance and Size}}$$

Bodek and Heywood (2008) estimated the traditional ERFC for France, Germany, Italy and the UK at about 50%. Such historical ERFC figures for the other countries selected for this research are not available. Given the discussion in Bodek and Heywood (2008), and the relative uniformity of vehicle model characteristics across Europe, it is appropriate to assume that all the selected countries have the same recent values of ERFC (of 50%).

2.3.2 Relative Fuel Consumption

This research considers the following powertrains in its analysis[4]: Naturally Aspirated Gasoline (NA-G), Turbocharged Gasoline (Turbo), Diesel, Full Gasoline Hybrid-Electric (HEV), Mild Gasoline Hybrid-Electric (mHEV), Diesel Hybrid-Electric (DHEV), Plug-in Hybrid (PHEV), Battery Electric (BEV) and Compressed Natural Gas (CNG) vehicles.

[4] Other powertrains that were left out of analysis are discussed in the Powertrain Sales Mix section.

The relative fuel consumptions of these powertrains and their future projections as shown in Figure 2.7 have been used for this research.

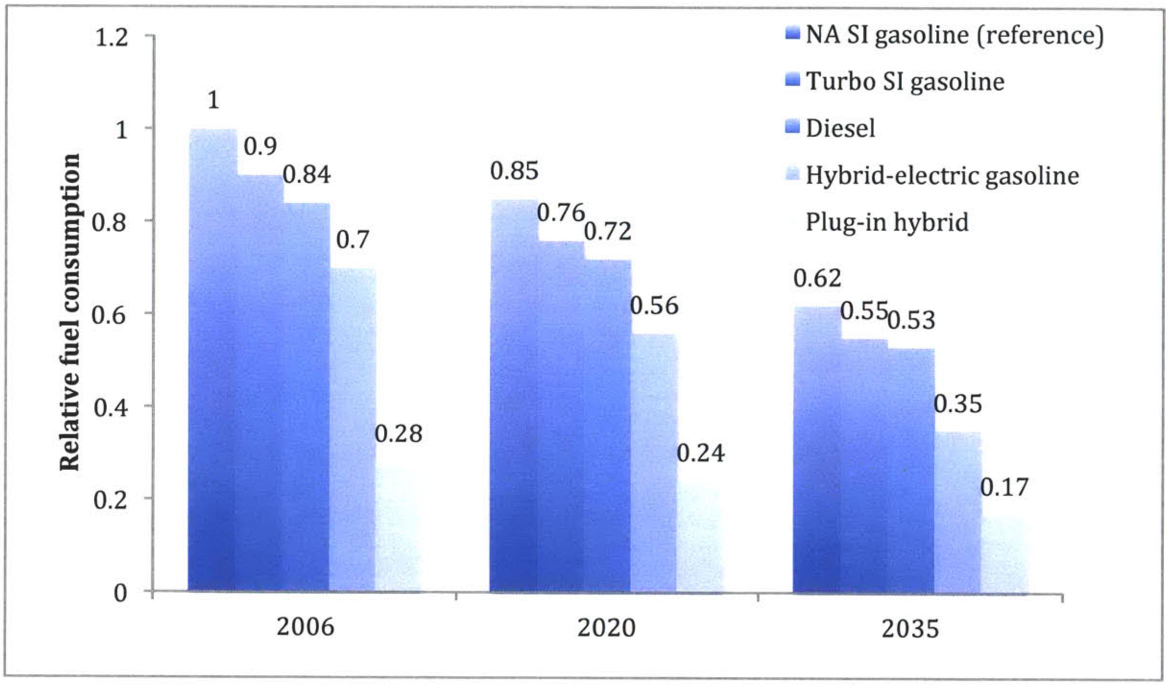

Fig. 2.7 Relative Fuel Consumption of Future Cars, By Powertrain Type (at 100% ERFC) [Heywood 2010] Sources: Kasseris and Heywood (2007), Kromer and Heywood (2007)

The relative FC values for year 2010 were obtained (see Table 2.4) by projecting improvements from 2006 with an ERFC of 50%:

Powertrain	Rel. FC (2006)	Rel. FC (2010) at 50% ERFC	Relative to 2010 NA-Gasoline
NA-G	1.00	0.97	1
Turbo	0.90	0.88	0.90
Diesel	0.84	0.82	0.84
HEV	0.70	0.67	0.68
PHEV	0.28	0.27	0.28

Table 2.4 Relative Fuel Consumption of Powertrains in 2010

Since the relative FC values for Mild Hybrid, Diesel Hybrid, CNG and BEV were not computed in the above-mentioned study, these were computed as follows:

Mild Hybrid

Mild Hybrid was assumed to have a fuel consumption value half way between a full hybrid and a NA Gasoline vehicle.

Diesel Hybrid

The FC value of Diesel Hybrid was computed by taking the average of two approaches –

i. First approach, modeling the Diesel Hybrid on a gasoline HEV and providing for the lower rate of improvement for a diesel engine.
   Since HEV was 30% better than NA-G in 2006, it was assumed that half of its benefit was due to hybrid and half was due to improvements in gasoline engine. It was assumed that while a Diesel Hybrid would enjoy the complete benefits of hybridization, the improvement in diesel engine would only be half that of a gasoline engine. This yielded a benefit factor

of (0.85 X 0.925) = 0.78[5]. Using this benefit factor, the diesel hybrid relative FC value was found out to be 0.7[6].

ii. Second approach, model the Diesel Hybrid on a gasoline HEV and use complete hybrid benefit. This approach yielded a relative value of 0.6[7] for Diesel Hybrid.

The average of the two values was 0.65, used as today's relative FC value for Diesel Hybrid. The diesel hybrid benefit factor of 0.76[8] was assumed to remain constant from 2006 to 2035, for the purpose of this analysis.

Compressed Natural Gas

The relative FC of a CNG vehicle is assumed to be the same as that of NA-G [US DOE 2010].

Battery Electric Vehicle

A BEV is assumed to have a relative FC of zero, since it is powered completely by electricity.

---

[5] First term, 0.85, represents 15% hybrid benefit. Second term, 0.925, represents half of 15% benefit due to gasoline engine improvement. This factor is closely in line with the reported 20% better fuel economy of diesel hybrids vis-à-vis diesel engines [JD Power 2008a].

[6] Obtained by multiplying the benefit factor with the relative FC of Diesel engine, i.e. 0.85

[7] Obtained by multiplying relative FC of Diesel engine, i.e. 0.85 with 0.7, i.e. the value denoting full gasoline hybrid benefit

[8] Obtained by dividing relative FC value of diesel hybrid with that of a diesel engine.

2.3.3 New Passenger Car Sales Mix

Today's Sales Mix

Today's New Passenger Car Sales Mix was derived by using the data from the EU CO_2 Monitoring Database [European Commission 2010c]. Table 2.5a, b show the raw New Passenger Car Sales data from the aforementioned database.

	Germany	UK	France	Italy
Petrol	1,687,964	1,177,890	463,194	914,736
Diesel	1,330,819	905,811	1,570,899	1,093,681
Electric	34	218		108
Natural Gas	8,463		74	8,166
Petrol-Bioethanol	8			
Petrol-LPG	13,756	65	2,054	145,572
Petrol-NG	3,317		395	
LPG		20		
Total New Cars	3,044,361	2,084,004	2,036,616	2,162,263

Table 2.5a New Passenger Car Sales For Selected Countries. Source: European Commission 2010c

	Spain	Netherlands	Portugal	Czech	Hungary
Petrol	316,041	357,752	66,429	98,804	115,673
Diesel	729,450	123,318	148,357	35,233	47,070
Electric					
Natural Gas			3		
Petrol-Bioethanol					
Petrol-LPG			27		
Petrol-NG			3	27	
LPG					
Total New Cars	1,045,491	481,070	214,819	134,064	162,743

Table 2.5b New Passenger Car Sales for Selected Countries. Source: European Commission 2010c

This data yielded Today's sales mix as shown in Table 2.6 below.

	Germany	UK	France	Italy	Spain	Netherlands	Portugal	Czech	Hungary
Petrol[9]	55.45%	56.02%	22.35%	48.54%	29.73%	73.87%	30.44%	73.21%	70.58%
Diesel	43.71%	43.46%	77.13%	50.58%	69.77%	25.63%	69.06%	26.28%	28.92%
Full Hybrid[10]	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
Electric[11]	-	-	-	-	-	-	-	-	-
CNG[12]	0.332%	-	-	0.378%	-	-	-	-	-

Table 2.6 Today's New Passenger Car Sales Mix

[9] Includes Petrol, Petrol-LPG, LPG, Petrol-Bioethanol, and half of Petrol-NG
[10] Assuming that there are 0.5% hybrid cars in Europe, all of which are Full Gasoline Hybrids
[11] Electric car numbers are insignificantly small, hence ignored
[12] CNG share represents the sum of Natural Gas and half the Petrol-NG share. CNG sales significant only in Italy and Germany; rest of the countries' numbers ignored.

The remaining part of this section describes the assumptions made for projecting the future sales mix of various types of new passenger cars.

Turbocharged Gasoline Cars

According to ABOUT Automotive, 10% of all new gasoline passenger cars in Europe were turbocharged in 2004. This number was expected to go up to 22% by 2010. Therefore, this research assumes today's share of turbocharged gasoline vehicles to be at 20% of all gasoline vehicles sold in Europe.

Moving further into the future, other estimates project the total turbocharged engines sold in Europe in 2014 at 70%-75% in 2014 [Motor Magazine 2009, SAE Article 2010]. This research makes a modest increase in the 2014-20 duration and assumes that a total of 80% of all cars solds in 2020 would be turbocharged. Since the average diesel car sales in Europe is expected to be between 42% and 50% by 2020[13] and all diesel cars are assumed to be turbocharged, this data can be extrapolated to show that roughly 55% of all gasoline cars will be turbocharged by 2020.

Diesel Cars

One of the important questions pertaining to Diesel engines in Europe is: going forward, would further dieselization of Europe happen?

Between 1990 and 2004, the relatively lower price of diesel fuel (in a high fuel price context) has been an important factor in increasing the share of diesel cars in new passenger car sales in Europe. The price of diesel has been below gasoline due to lower taxes on it in most of Europe. This leads to a favorable relative cost of diesel ownership even after considering higher purchase costs of diesel cars and higher production cost of diesel [Pock 2009].

[13] Based on EU historical sales data, Scenarios developed by this research and Diesel penetration estimates discussed later in the thesis.

However, over the years, the price differential between the pre-tax price of diesel and gasoline has steadily increased (Fig. 2.8).

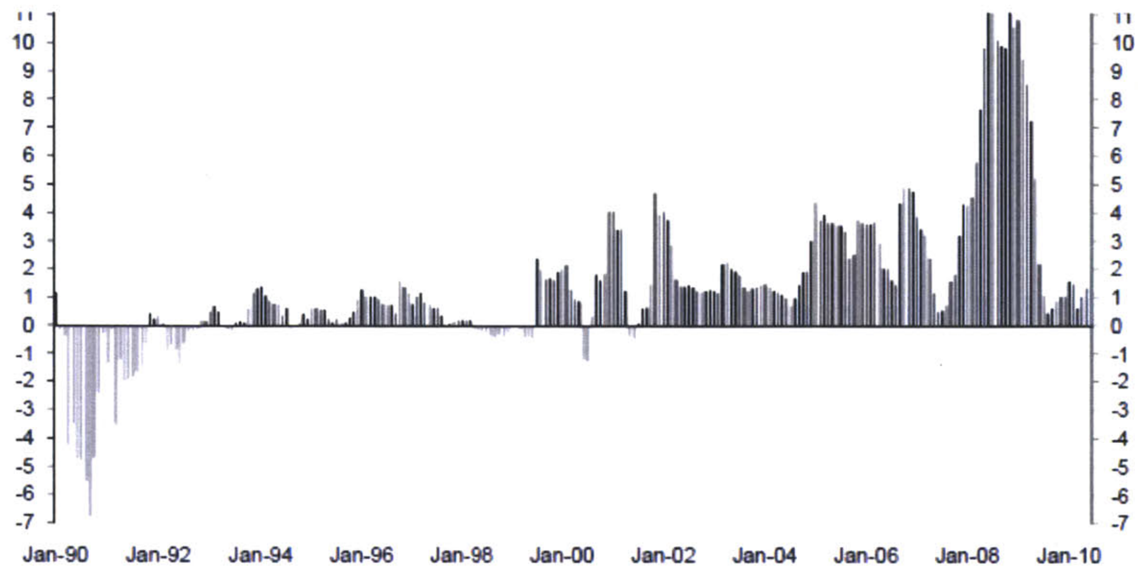

Fig. 2.8 Difference in the pre-tax price of diesel and petrol in pence – excess of diesel over petrol (pence per litre) [UK Parliament 2010] Source: Quarterly Energy Prices, DECC

This relative increase in the price of diesel is attributed to a long-term increase in demand for diesel coupled with limited diesel refining capacity [UK Parliament 2010]. In January 2008, in 14 out of 27 countries in Europe, diesel was more expensive than gasoline, although as of June 2010, only UK had diesel more expensive than gasoline. [Autoblog Green 2008, UK Parliament 2010]. While the diesel prices in recent months have fallen, they still remain subject to the longer term price increase trend. JD Power (2008) estimates that the growth in diesel vehicle demand in Western Europe has passed its peak. Any increase in sales was expected to be modest over the 2008-10 period, followed by declines later.

However, in other parts of Europe, diesel share was seen to experience "considerable growth", moving from 19% in 2002 to 42% in 2007 [JD Power 2008]. While others may not agree with the assessment that Diesel car share increase has passed its peak, they do concede that any future growth would be more moderate [AID 2008]. Also, gasoline engine improvements over the next decade (and an increase in the share of turbo-gasoline engines) narrows the diesel-gasoline efficiency difference significantly.

Keeping the above in mind, we believe that diesel car sales in Europe would move to an average of 50% by 2020. For modeling purposes, the countries that currently have a diesel share of greater than 50% will lower the share and the countries with less than 50% of current diesel share will increase the share.

Hybrid Cars

Like for most new technologies, there are wide ranging estimates for penetration rate of Hybrids in Europe. These estimates range from a low of 2% in 2015 to 20% (including electric vehicles) in 2020 (Fig. 2.9a, 2.9b and 2.9c)[Hybrid Cars Article 2008, JD Power 2008a, Reuters 2010].

This research assumes the total hybrid penetration to be a maximum of 15% in 2020. This figure includes Gasoline Hybrids (Full/Mild) and Diesel Hybrids. For the purpose of this study, the "stop and start" Micro Hybrids are considered part of the improvement in conventional gasoline engine. This view is in line with that of some manufacturers, who distinguish such improvements from benefits offered by Mild or Full Hybrids [Hybrid Cars Article 2007].

Mild Gasoline Hybrids are likely to penetrate faster and sooner than Full Gasoline Hybrids owing both to their lower cost and manufacturers' declared focus [Autoweek 2007b, Reuters 2010]. Diesel Hybrids are inherently more expensive than equivalent full Gasoline Hybrids. However, Diesel Hybrids might be better suited to Europe than Gasoline Hybrids [JD Power 2008a, Autoweek 2007a], and, according to Frost & Sullivan, European customers might be more willing to buy them, provided the manufacturers are able to bring affordable models to market [Autoweek 2007a, Green Car Congress 2007].

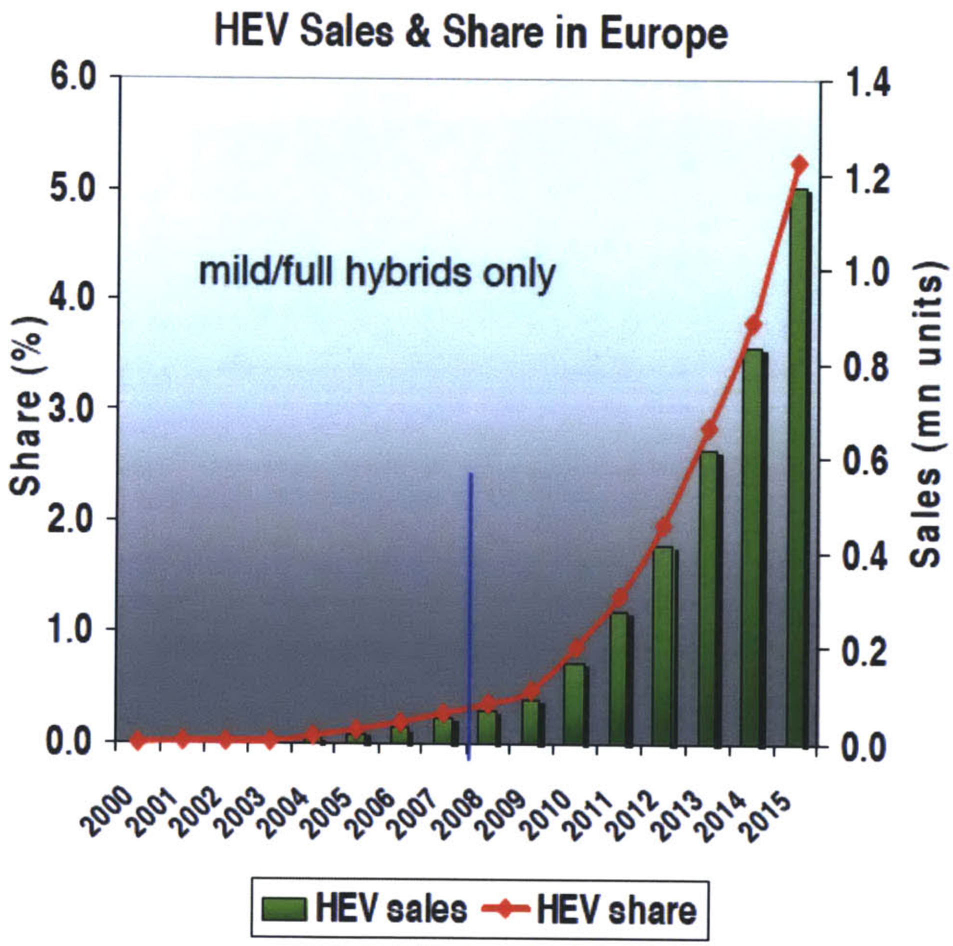

Fig. 2.9a Europe HEV Forecast - Optimistic Scenario

Source: JD Power 2008a

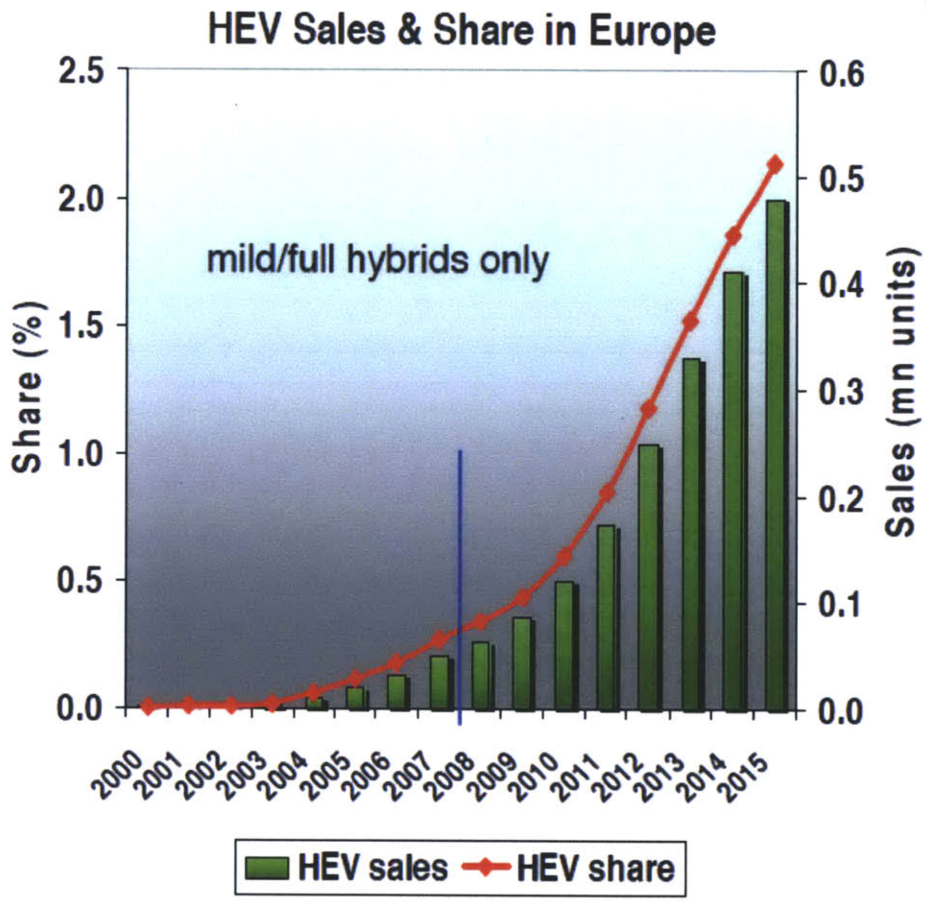

Fig. 2.9b Europe HEV Forecast - Pessimistic Scenario

Source: JD Power 2008a

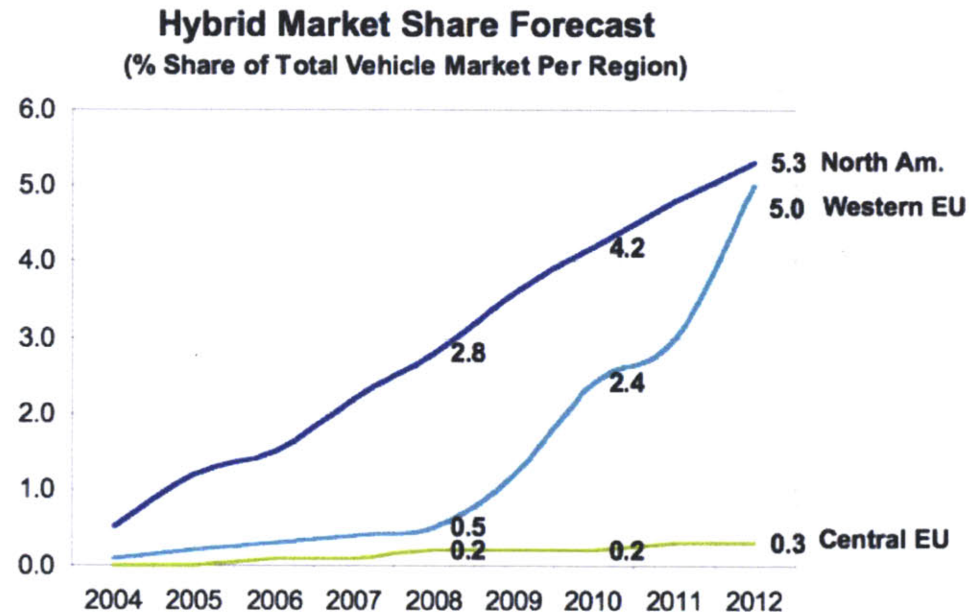

Fig. 2.9c Europe HEV Forecast

Source: Hybrid Cars Article 2008

CNG Cars

Currently, the highest CNG sales share exists in Italy – about 0.4%[14], a relatively small number. For the purpose of this study, it was assumed that, at the maximum, the CNG share in new car sales would rise to this level in all selected countries by 2020. Further, it was assumed that the CNG share in Italy would remain constant at 0.4%. All in all, these assumptions would bring the 2020 EU average of CNG share to roughly 2.5 times the current EU average of 0.16%.

[14] 0.378%

Electric Cars

Figure 2.10 shows that some estimates peg the Electric Car market share between 6% and 8% in the EU in year 2020.

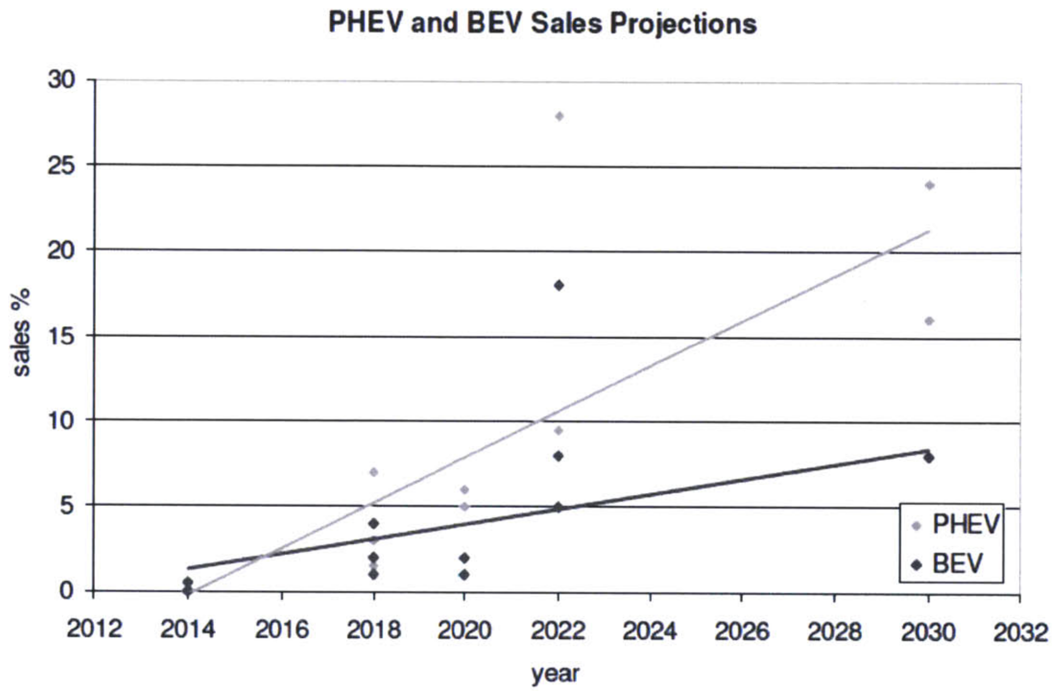

Fig. 2.10 PHEVs and BEVs Sales Projection in the EU. Source: BCG, AEA [de Sisternes 2010]

Others believe that the combined market share of Electric Cars and Hybrids would be 15% in 2020 [Reuters 2010].

Keeping these opinions in mind, this study assumes the potential market share of Electric Cars to be a maximum of 8% in 2020. This study also expects PHEVs to outsell BEVs during this timeframe owing largely to their relatively lower costs [de Sisternes 2010] and their lack of any overall driving range limitation.

Other Cars

We would like to acknowledge that cars running on several other alternative technologies/fuels exist today and might continue to proliferate in future. However, this study chooses to ignore them in order to focus on those types that either already have a significant market share or are projected to acquire a sizeable market share during the timeframe under consideration. Thus, some powertrain and fuel types left out of this analysis are LPG cars (insignificant current market share; no widespread adoption in EU foreseen by 2020), Hydrogen Fuel Cell cars (Insignificant, if any, market share expected by 2020), and dedicated Biofuels cars (relatively modest market share expected by 2020).

2.3.4 Weight and Drag Reduction Impact

One important way to reduce fuel consumption is to reduce the weight of the vehicle, thereby reducing the inertial forces that the engine has to overcome. Similarly, a reduction in the vehicle's aerodynamic drag and tire rolling resistance leads to improvement in fuel consumption. For a detailed introduction to this topic, the reader is referred to Heywood (2010).

A previous study (Cheah, et al 2007) found that for every 10% reduction of a vehicle's weight, its fuel consumption decreases by 0.3 L/100km, in the case of passenger cars. Moreover, the maximum total weight reduction possible going forward to year 2035 was estimated to be 35% from today's vehicle weight in the U.S. context. These results were adapted to be appropriate for the average (smaller size and lighter) European car. Finally, this research maintains the assumption of Kasseris and Heywood (2007) for a 20% reduction in vehicle weight by 2035 for the 100% ERFC case. Values of weight reduction, when ERFC is below 100%, are computed by scaling ERFC. [Cheah, et al 2008]

2.3.5 Scenarios

In order to explore the ease or difficulty of meeting the emissions targets, this study creates several possible future scenarios and compares the emissions reductions achieved in each one of them. Since the aim of this study is to illustrate the relative ease or difficulty of achieving the targets, three scenarios are created –

- **Realistic**: paints a realistic picture of vehicle sales mix, ERFC and vehicle weight reduction that we anticipate would be achieved by 2020,
- **Optimistic**: a scenario that is more optimistic in nature and requires faster rates of change in technology, and
- **Fixed Sales Mix**: a scenario that provides the base case for comparison by assuming no change from today's powertrain sales mix, an ERFC constant at today's level of 50%, and no additional vehicle weight reduction above that achieved due to ERFC.

It is important to note that these scenarios are not meant to forecast or predict. Instead, they are used as examples to illustrate the relative ease or difficulty in achieving the emissions targets and sensitivity to rates of technology change.

Average European Scenarios

First a set of average European scenarios was evolved. Table 2.7 lists the average European scenarios for the year 2020. The sales mix for 2015 is half way between the today and 2020 sales mixes.

	Today	Scenarios Optimistic 2020	Realistic 2020
ERFC	50%	75%	50%
Weight Reduction (Total)		10%	5%
New Car Sales Mix			
Gasoline	**46.68%**	**34%**	**41%**
Non-turbo Gasoline	37.34%	14%	25%
Turbo Gasoline	9.34%	20%	16%
Diesel	**52.66%**	**42%**	**50%**
Hybrid	**0.5%**	**15%**	**6%**
Mild Hybrid		6%	4%
Full Hybrid	0.5%	6%	2%
Diesel Hybrid		3%	
Electricity	**0%**	**8%**	**2%**
PHEV		5%	2%
BEV		3%	
CNG	**0.16%**	**0.4%**	**0.4%**
	100.00%	100.00%	100.00%

Table 2.7 Average European New Vehicle Sales Scenarios In Year 2020

The values of New Car Sales Mix for "Today" are obtained from the EU CO_2 Monitoring Database [European Commission 2010c]. The ERFC value of "Today" is based on Europe's traditional ERFC of 50%, as stated elsewhere in this thesis.

The Realistic scenario is built by assuming that the ERFC will remain at the current level and there will be relatively lower emphasis on vehicle weight reduction. In terms of new passenger car sales mix, this scenario illustrates a case where new technologies (Hybrid/Electric) have not been able to penetrate significantly by 2020. Turbocharged Gasoline cars will only be able to penetrate to about 30% (i.e. half the maximum level assumed in this thesis) of all gasoline cars sold. Diesel car share would remain about the same at 50%. Hybrid and Electric cars will have a low penetration rate, with Mild Gasoline Hybrids leading the way and Diesel Hybrids and BEVs unable to make a mark. CNG cars would remain at 0.4% of all the new cars sold.

The Optimistic scenario assumes that there will be a higher emphasis on reducing fuel consumption (75%) and a greater amount of vehicle weight will be reduced. Turbocharged Gasoline cars will reach up to 60% of all gasoline cars sold by 2020. In addition, new technologies like Hybrid and Electric cars will be able to achieve the maximum penetration levels assumed in this thesis. As they do so, they will take equally from gasoline and diesel market shares. In this scenario, Full Gasoline Hybrids will be able to equal the sales of Mild Gasoline Hybrids due to a larger number of models available and cheaper hybrid technology. Diesel Hybrids will have a significant market share at roughly half of the Full Gasoline Hybrids. Finally, BEVs will achieve a market share roughly equal to half the PHEV market share.

Country Specific Scenarios

The "Today" values for the countries are determined from EU CO_2 Monitoring Database [European Commission 2010c].

For the Optimistic and Realistic scenarios, since all the selected countries have negligible current market shares of Hybrids, Electric cars and CNG, it was assumed that all these countries would exhibit similar adoption of these technologies. Hence, for these technologies, all of the countries would move towards these average European scenario values.

The countries, however, would differ in their Diesel car market share. Those countries that currently have a lower Diesel car market share than the average European value would move half the way up to the average European Diesel car market share value by 2020. And those countries that currently have a higher Diesel car market share than the average European value would move half the way down to the average European Diesel car market share value by 2020.

The rest of the market share will be that of the Gasoline cars, of which 60% and 30% will be turbocharged for Optimistic and Realistic scenarios, respectively.

2.3.6 Model Calibration

Once the model was set, it was calibrated against reported emissions results obtained from the EU CO_2 emissions monitoring database [European Commission 2010c]. Figure 2.11 shows that the emissions computed by the model for every country for "Today" are in close agreement with those reported by those countries to the European Commission.

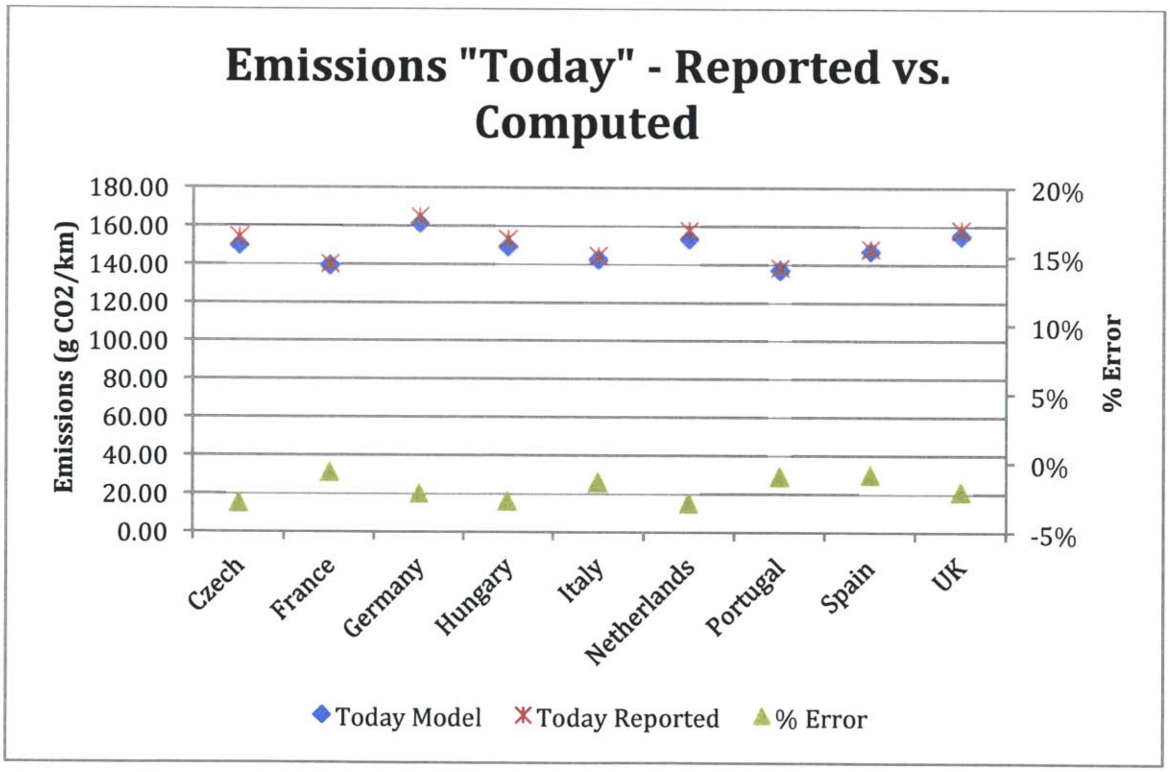

Fig. 2.11 Model Calibration Against EU Reported CO_2 Emissions

3. Customized Fleet Model

The customized fleet model developed for this research has its origins in the work of Bodek and Heywood (2008). The original fleet model has been modified to incorporate new powertrains like Mild Hybrid, PHEV and BEV. Further, the new car sales assumptions have been suitably changed to yield a penetration rate and sales mix as developed and described in the CO_2 Emissions Model summarized in the previous chapter. The model is used to provide projections for the following:

- Fuel Use Reduction Potential for both Optimistic and Realistic scenarios, and
- Diesel to Gasoline Fuel Ratio for Optimistic, Realistic and Fixed Sales Mix scenarios

Four countries, Germany, UK, Italy, and France, were selected for analysis in this way given both their large existing fleets and the significant differences in their historical and "Today's" new passenger car sales mix.

Table 3.1 – 3.4 list the "Today", Optimistic, Realistic and Fixed Sales Mix scenarios for Germany, France, Italy, and UK, respectively.

		Scenarios	
	Today/ Reference	**Optimistic 2020**	**Realistic 2020**
ERFC	50%	75%	50%
Weight Reduction (Total)		10%	5%
Due to ERFC		3%	2%
Additional	0%	7%	3%
New Car Sales Mix			
Gasoline	**55.46%**	**33.77%**	**44.77%**
Non-turbo Gasoline	44.37%	13.51%	31.34%
Turbo Gasoline	11.09%	20.26%	13.43%
Diesel	**43.71%**	**42.86%**	**46.86%**
Hybrid	**0.5%**	**15.00%**	**6.00%**
Mild Hybrid	0.00%	6.00%	4.00%
Full Hybrid	0.5%	6.00%	2.00%
Diesel Hybrid	0.00%	3.00%	0.00%
Electricity	**0%**	**8.00%**	**2.00%**
PHEV	0.00%	5.00%	2.00%
BEV	0.00%	3.00%	0.00%
CNG	**0.33%**	**0.38%**	**0.38%**
	100.00%	100.00%	100.00%

Table 3.1 Scenarios for Germany

		Scenarios	
	Today/ Reference	**Optimistic 2020**	**Realistic 2020**
ERFC	50%	75%	50%
Weight Reduction (Total)		10%	5%
Due to ERFC		3%	2%
Additional	0%	7%	3%
New Car Sales Mix			
Gasoline	**22.37%**	**17.06%**	**28.06%**
Non-turbo Gasoline	17.90%	6.82%	19.64%
Turbo Gasoline	4.47%	10.23%	8.42%
Diesel	**77.13%**	**59.57%**	**63.57%**
Hybrid	**0.5%**	**15.00%**	**6.00%**
Mild Hybrid	0.00%	6.00%	4.00%
Full Hybrid	0.5%	6.00%	2.00%
Diesel Hybrid	0.00%	3.00%	0.00%
Electricity	**0%**	**8.00%**	**2.00%**
PHEV	0.00%	5.00%	2.00%
BEV	0.00%	3.00%	0.00%
CNG	**0.0%**	**0.38%**	**0.38%**
	100.00%	100.00%	100.00%

Table 3.2 Scenarios for France

		Scenarios	
	Today/ Reference	**Optimistic 2020**	**Realistic 2020**
ERFC	50%	75%	50%
Weight Reduction (Total)		10%	5%
Due to ERFC		3%	2%
Additional	0%	7%	3%
New Car Sales Mix			
Gasoline	**48.54%**	**30.33%**	**41.33%**
Non-turbo Gasoline	38.83%	12.13%	28.93%
Turbo Gasoline	9.71%	18.20%	12.40%
Diesel	**50.58%**	**46%**	**50%**
Hybrid	**0.50%**	**15%**	**6%**
Mild Hybrid	0.00%	6%	4%
Full Hybrid	0.50%	6%	2%
Diesel Hybrid	0.00%	3%	0%
Electricity	**0%**	**8%**	**2%**
PHEV	0.00%	5%	2%
BEV	0.00%	3%	0%
CNG	**0.38%**	**0.38%**	**0.38%**
	100.00%	100.00%	100.00%

Table 3.3 Scenarios for Italy

	Scenarios		
	Today/ Reference	**Optimistic 2020**	**Realistic 2020**
ERFC	50%	75%	50%
Weight Reduction (Total)		10%	5%
Due to ERFC		3%	2%
Additional	0%	7%	3%
New Car Sales Mix			
Gasoline	**56.04%**	**34.39%**	**44.89%**
Non-turbo Gasoline	44.83%	13.76%	31.42%
Turbo Gasoline	11.21%	20.64%	13.47%
Diesel	**43.46%**	**42.23%**	**47%**
Hybrid	**0.50%**	**15%**	**6%**
Mild Hybrid	0.00%	6%	4%
Full Hybrid	0.50%	6%	2%
Diesel Hybrid	0.00%	3%	0%
Electricity	**0%**	**8%**	**2%**
PHEV	0.00%	5%	2%
BEV	0.00%	3%	0%
CNG	**0.00%**	**0.38%**	**0.38%**
	100.00%	100.00%	100.00%

Table 3.4 Scenarios for UK

The framework of the model relevant to this research is shown in figure 3.1 below. The orange blocks of the framework represent the parts that have been modified for this study.

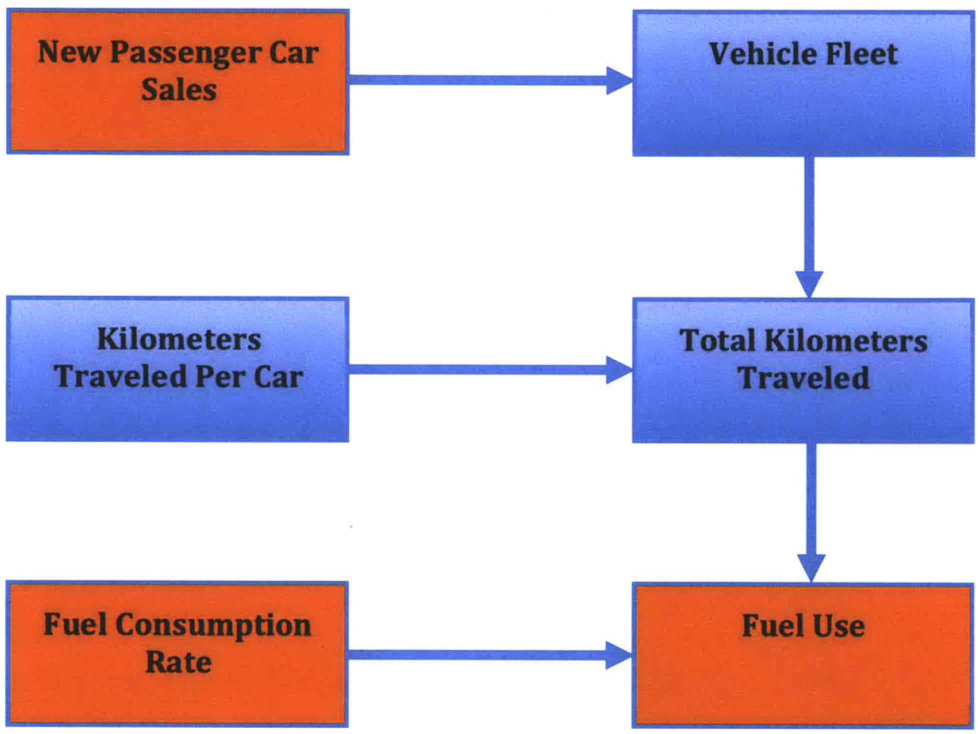

Fig. 3.1 Fleet Model Framework

The reader is advised to peruse Bodek and Heywood (2008) for a detailed summary of the model framework and the core assumptions built therein. The following sub-section describes the assumptions and modifications specific and relevant to this study.

3.1 New Passenger Car Sales

This component of the fleet model framework focuses on modeling the current and future powertrain-based composition of the passenger car market. The original fleet model provided for NA Gasoline, Turbocharged Gasoline, Diesel, Full Gasoline Hybrid-electric, Diesel Hybrid, and CNG powertrains. In order to prepare the model to fit the requirements of the powertrain-mix as used in this research, the following two steps were carried out for Germany, France, Italy and UK:

a. Addition of new powertrains to the model,
b. Update of the current and future powertrain sales mix

3.1.1 Addition Of New Powertrains To The Model

Mild Gasoline Hybrid-electric, PHEV and BEV powertrains were added to the original model. The "Today", i.e. 2010, market share of all the three powertrains was zero percent. All three were assumed to begin penetrating the market linearly from 2010 onwards and achieve the 2020 target market share. Consequently, there was no market share of any one of these powertrains prior to 2010.

3.1.2 Update Of The Current And Future Powertrain Sales Mix

NA Gasoline, Gasoline Turbocharged, and Diesel powertrains were assumed to linearly progress (increase or decrease) from their 2005 sales mix values to the updated 2010, i.e. "Today", sales mix values. Beginning from 2010, these powertrains were assumed to progress (increase or decrease) linearly for 10 years such that they achieved the 2020 target sales mix values.

Full Gasoline Hybrid, Diesel Hybrid and CNG were presumed to be negligible prior to 2010, and adjusted accordingly. These powertrains too penetrated linearly over the next 10 years to ultimately reach the 2020 sales mix values.

"Today" sales mix values for all the powertrains were obtained from European Commission (2010c). 2020 sales mix values were derived from the Optimistic and Realistic scenarios for the respective countries.

3.2 Fuel Consumption Rate

3.2.1 Mild Gasoline Hybrid-electric

Both, "Today" and 2020 fuel consumption rate for Mild Gasoline Hybrid-electric powertrain was kept consistent with the assumption in the CO_2 Emissions Model discussion; i.e. the relative fuel consumption of a Mild Gasoline Hybrid-electric powertrain was midway between those of NA Gasoline and Full Gasoline Hybrid-electric powertrains. The fuel consumption rate values varied linearly between 2010 and 2020.

3.2.2 PHEV And BEV

This study considers the PHEV powertrain to be powering a 30km battery-electric range vehicle with a utility factor of 0.5. This means that these vehicles drive on average half their kilometers driven in charge depleting mode and the other half in gasoline hybrid mode. Therefore, the fuel consumption of a PHEV is the sum of two parts:

a. electricity consumption (in gasoline equivalent terms), plus
b. gasoline hybrid consumption

Gasoline consumption is found using the gasoline consumption rates for such a PHEV shown in Table 3.3 using results from De Sisternes (2010):

Year	Gasoline Consumption (L/100km)
2010	2.51
2020	2.05
2035	1.37

Table 3.3 PHEV Gasoline Consumption Rates

Electricity consumption is found using the electricity consumption rates for a pure electric vehicle (i.e. BEV) as shown in Table 3.4 using results from De Sisternes (2010):

Year	Electricity Consumption (Wh/km)
2010	160
2020	156
2035	150

Table 3.4 BEV Electricity Consumption Rates

The electricity consumed is kept separate from the total petroleum consumption. To determine the corresponding gasoline equivalent, standard energy density value of gasoline, 32 MJ/l, is used.

3.3 Fuel Use

In order to compute the fuel use for Mild Gasoline Hybrid-electric, PHEV and BEV, it was assumed that the VKT (Kilometers traveled per vehicle) of these powertrains was the same as that for a Full Gasoline Hybrid-electric vehicle operating in that country. Similarly, the scrappage rate was assumed to be the same as that for a Full Gasoline Hybrid-electric vehicle. The country-wise VKT values [Bodek and Heywood 2008] for the various powertrains used in the model are shown in Tables 3.5 - 3.8 below:

Powertrain	VKT (km/year)
NA Gasoline, Turbo Gasoline, Full Gasoline Hybrid, Mild Gasoline Hybrid, Diesel Hybrid, PHEV, BEV, CNG	15478
Diesel	22840

Table 3.5 VKT Values for Germany

Powertrain	VKT (km/year)
NA Gasoline, Turbo Gasoline, Full Gasoline Hybrid, Mild Gasoline Hybrid, Diesel Hybrid, PHEV, BEV, CNG	15446
Diesel	21038

Table 3.6 VKT Values for France

Powertrain	VKT (km/year)
NA Gasoline, Turbo Gasoline, Full Gasoline Hybrid, Mild Gasoline Hybrid, Diesel Hybrid, PHEV, BEV, CNG	15533
Diesel	24995

Table 3.7 VKT Values for Italy

Powertrain	VKT (km/year)
NA Gasoline, Turbo Gasoline, Full Gasoline Hybrid, Mild Gasoline Hybrid, Diesel Hybrid, PHEV, BEV, CNG	18732
Diesel	28681

Table 3.8 VKT Values for UK

For the purpose of this study, it is assumed that these VKT values remain constant through the period under consideration, i.e. 2010-2020.

These VKT values show that Diesels are run about 48%, 36%, 61%, and 53% more than the cars with other powertrains in Germany, France, Italy and UK, respectively. Therefore, an increase in Diesels in the given timeframe would lead to a higher overall VKT and hence higher Fuel Use, whereas a decrease in Diesels in the given timeframe would lead to a lower overall VKT and lower Fuel Use.

The fuel use of individual powertrains over the timeframe under consideration (2010 – 2020) was integrated to obtain the overall fuel use figures for a given scenario for a country.

4. Results

4.1 Feasibility Of Achieving The 2015 And 2020 CO_2 Emissions Targets

Figure 4.1 shows the projected emissions computed for each country and for each scenario in year 2015.

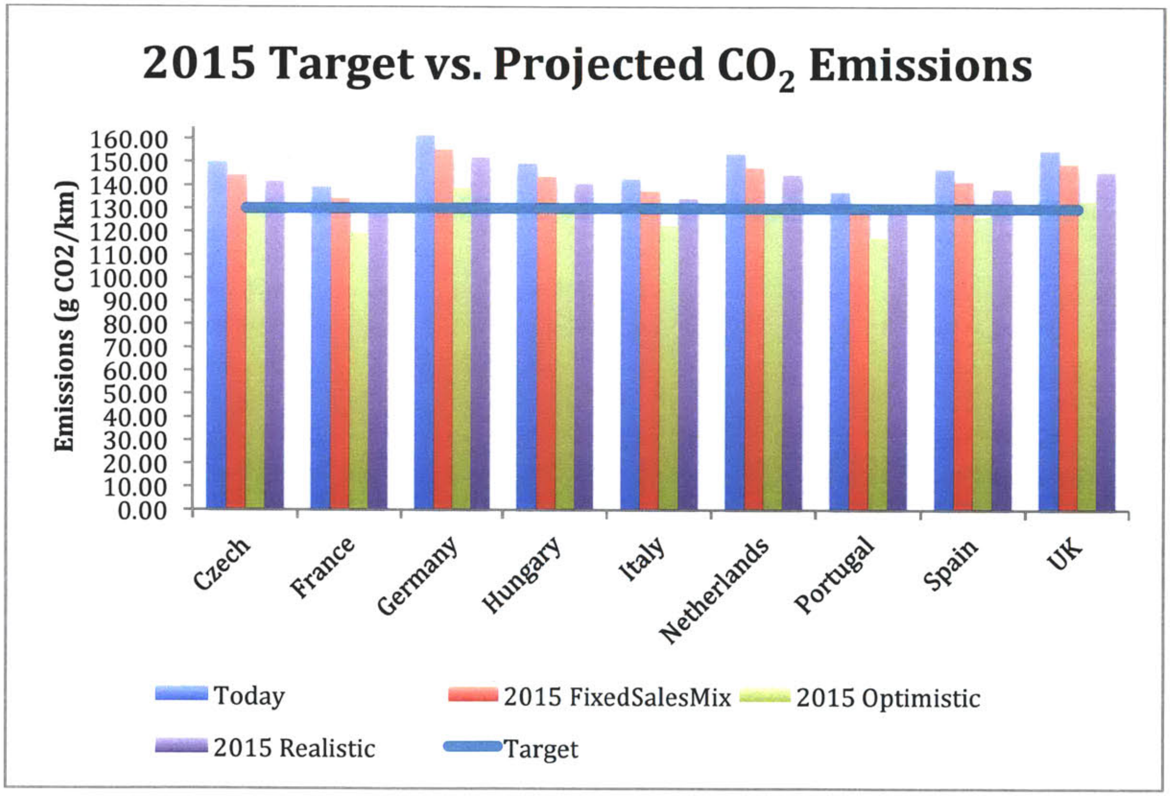

Fig. 4.1 Target vs. Projected CO_2 Emissions - 2015

Figure 4.2 shows the projected emissions computed for each country and for each scenario in year 2020.

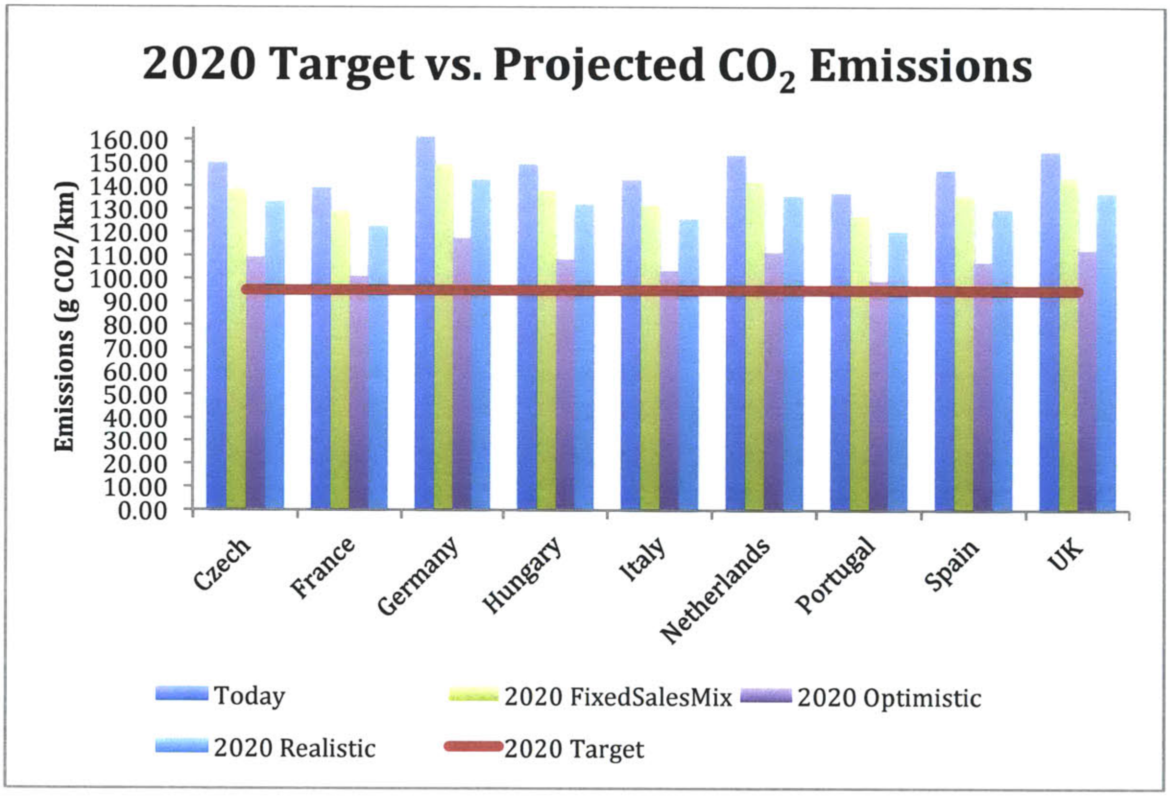

Fig 4.2 Target vs. Projected CO_2 Emissions - 2020

These results show that it appears feasible to meet the 2015 target in all countries in at least the optimistic scenario except for Germany and (maybe) the UK. Germany would be able to lower its emissions by only about 72% of the required amount and be stranded at 138 g CO_2/km in the optimistic scenario. It would face a 2-year delay in meeting the 2015 target. UK would perhaps almost be able to meet the 2015 target by lowering its emissions to 133 g CO_2/km by 2015, and will be poised to meet the target within the next year.

However, the optimistic scenario assumes a significant penetration of new technologies like PHEVs and BEVs, accompanied with a 75% emphasis on reduction of fuel consumption – 50% more than the historical value. Both of these assumptions indicate a tough task for the car manufacturers given that currently PHEVs and BEVs are virtually non-existent in the European consumer market and historically the ERFC in Europe has lingered around 50% for a long time and a sudden "shift in gears" would be challenging.

In the realistic scenario for 2015, the targets will be met only in Portugal and France by 2015. Italy will almost make it, but it would take another two years to meet the 2015 target under the realistic scenario. All other countries face a delay of several years. Germany, UK, Hungary, Czech and Netherlands will meet the target long after 2020. Spain would be delayed by four years in the realistic scenario.

The situation looks less promising for the 2020 CO_2 emissions target. The results show that it would not be possible to meet the target in any of the countries under any of the scenarios analyzed. In the optimistic scenario, Portugal's new passenger car CO_2 emissions will come closest to meeting the 2020 target by reaching a level of about 100 g CO_2/km.

The results also show that the 2020 emissions target is far more demanding than the 2015 target. Hence, from an auto manufacturer's perspective, a relatively slower emission reduction effort up to 2015 could lead to the need for employing a substantially higher post-2015 emissions reduction effort leading to 2020, if the EU decides to keep the 2020 target at its current value after the proposed review in 2013.

4.2 What Would It Take To Meet The Targets?

In order to explore how the 2015 and 2020 targets could be met by using different sales mixes, we created additional scenarios by varying the sales fraction of only one powertrain at a time. Any increase in this powertrain's share would come equally from the gasoline and diesel market shares. For this analysis, we considered HEV, PHEV and BEV since these are the three best powertrains in terms of reducing fuel consumption. The Optimistic scenario provided the "base" for developing these additional scenarios.

Table 4.1 shows the approximate relative improvement achieved by increasing the market share of the individual power trains by 1 percentage point each.

Powertrain	Improvement in CO_2 Emissions
HEV	-0.17%
PHEV	-0.40%
BEV	-1%

Table 4.1 Relative Effectiveness of Powertrains In Improving CO_2 Emissions

In other words, BEV and PHEV would be roughly 6 times and 2.3 times more effective than an HEV in reducing vehicle sales-mix CO_2 emissions in Europe.

Applying these results, it is seen that the 2015 target can be met in Germany by employing any of the following options:

a. 42% of new cars should be HEV by 2020, or
b. 21% of new cars should be PHEV by 2020, or
c. 9% of new cars should be BEV by 2020

It should be noted here that this is just a computation to compare the tank to wheel effectiveness of one technology over the others. This is not meant to suggest that, for example, a 9% BEV target should be kept for the German marketplace, since that kind of a target would also need careful analysis of Well-To-Wheel emissions for all the technologies.

4.3 Country Specific Feasibility

Figures 4.3 through 4.11 illustrate the projected new passenger car carbon emissions for each country and for each scenario for the whole period from Today to 2020.

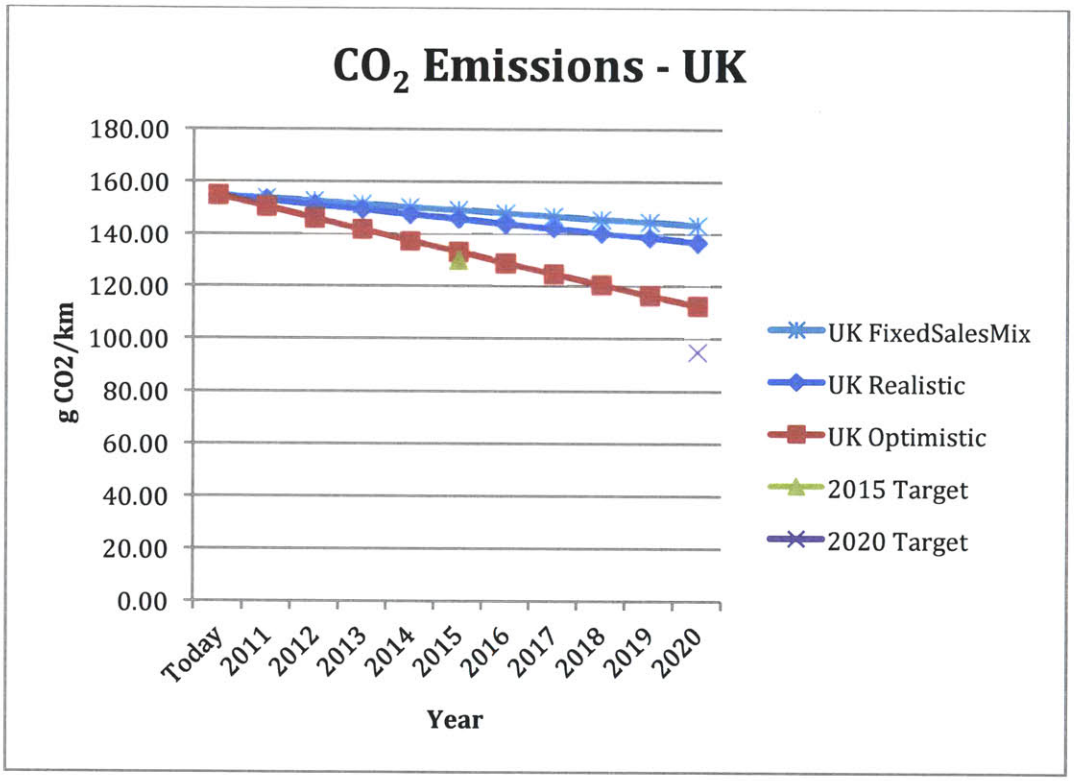

Fig 4.3 Projected CO_2 Emissions - UK

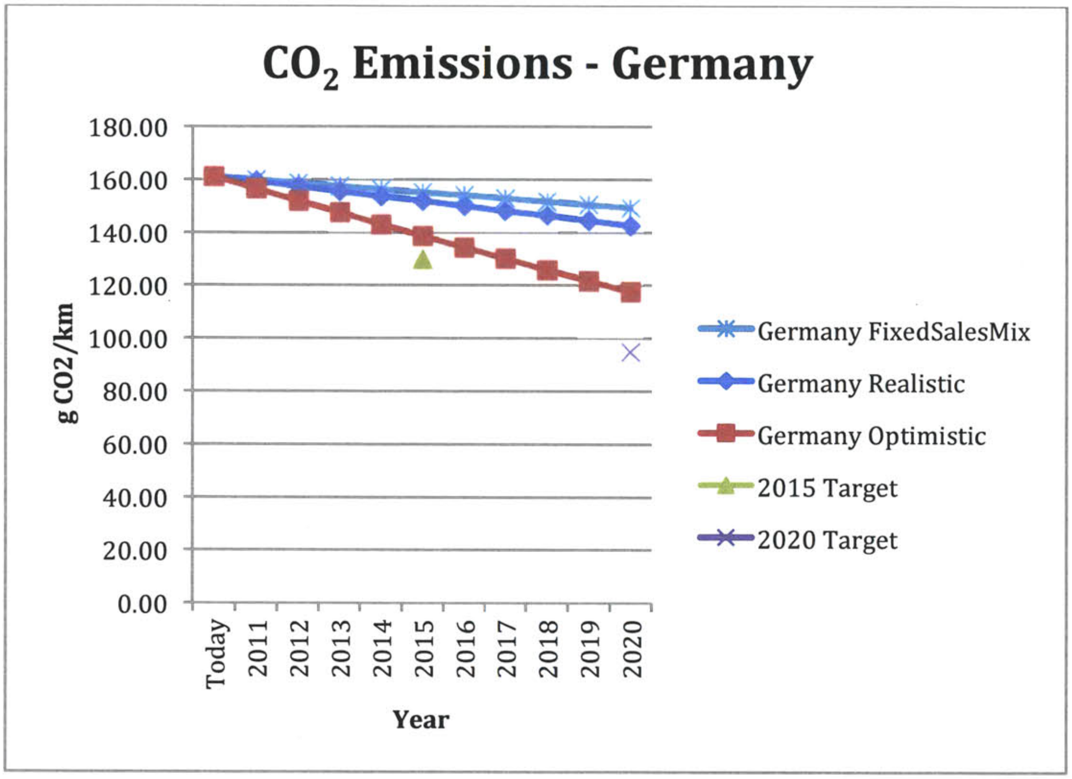

Fig 4.4 Projected CO_2 Emissions – Germany

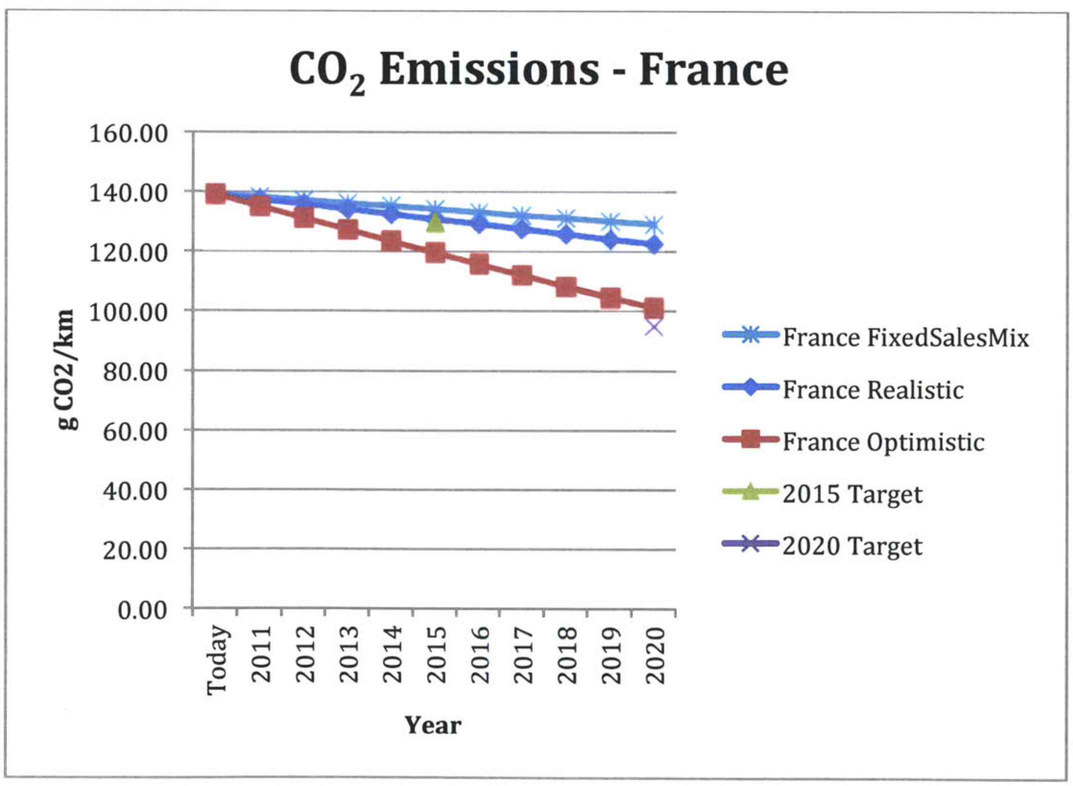

Fig 4.5 Projected CO_2 Emissions – France

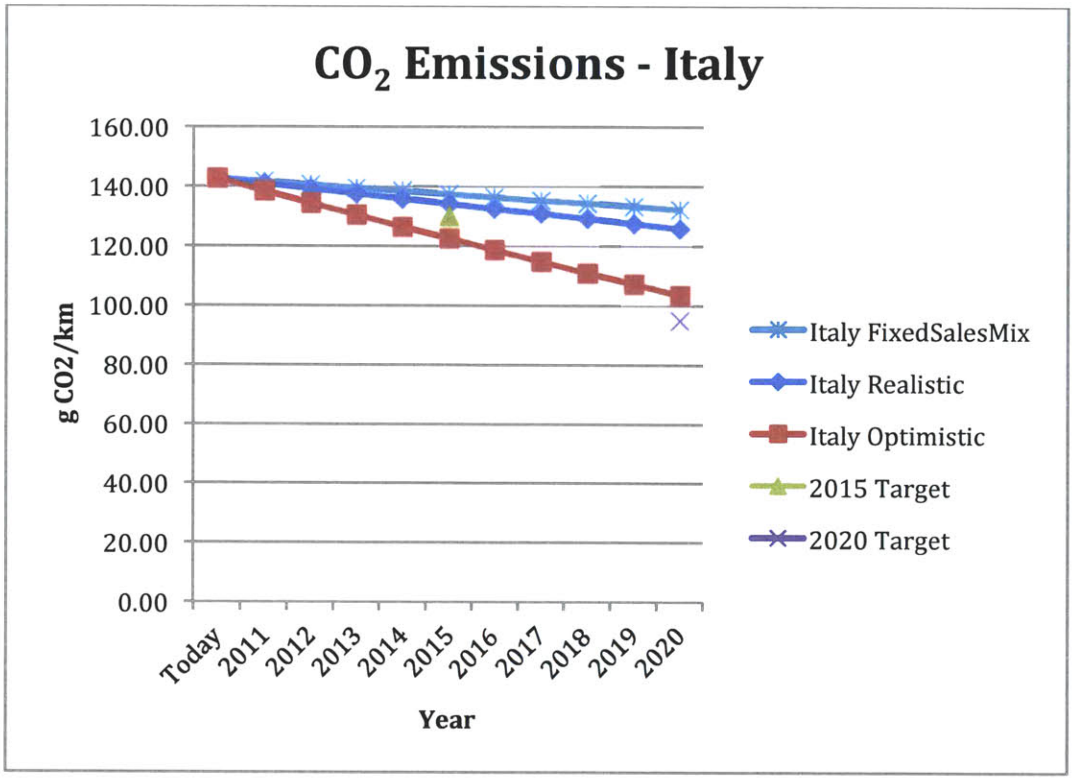

Fig 4.6 Projected CO_2 Emissions - Italy

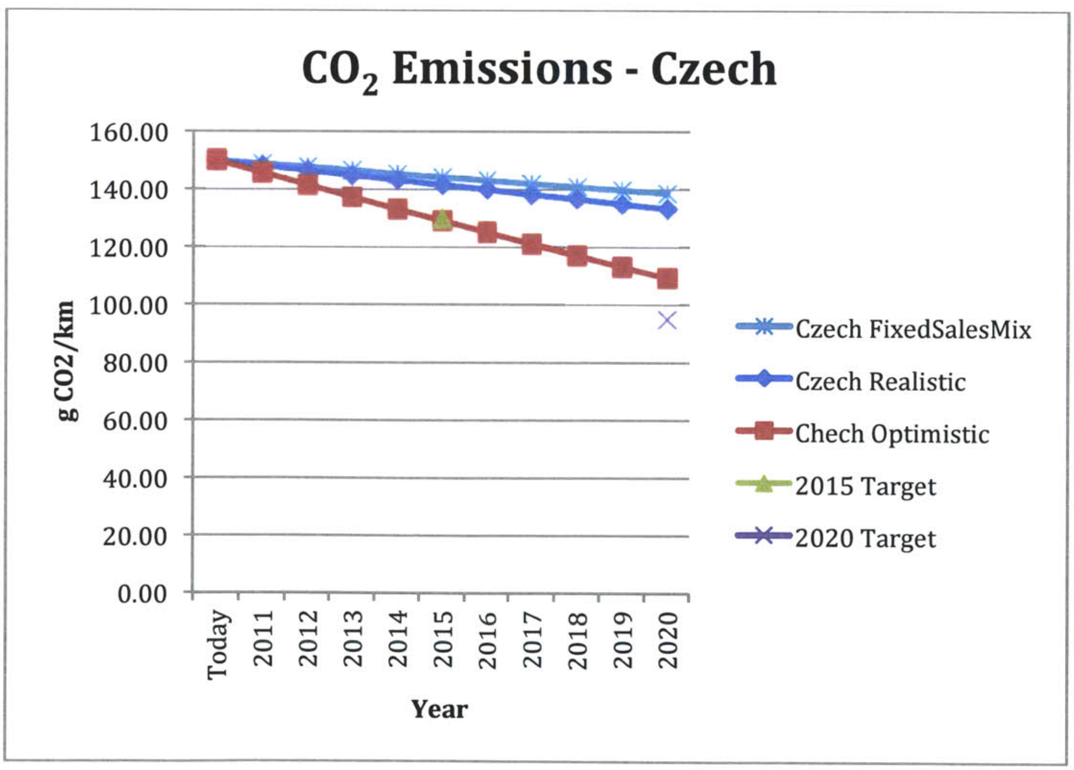

Fig. 4.7 Projected CO_2 Emissions – Czech Republic

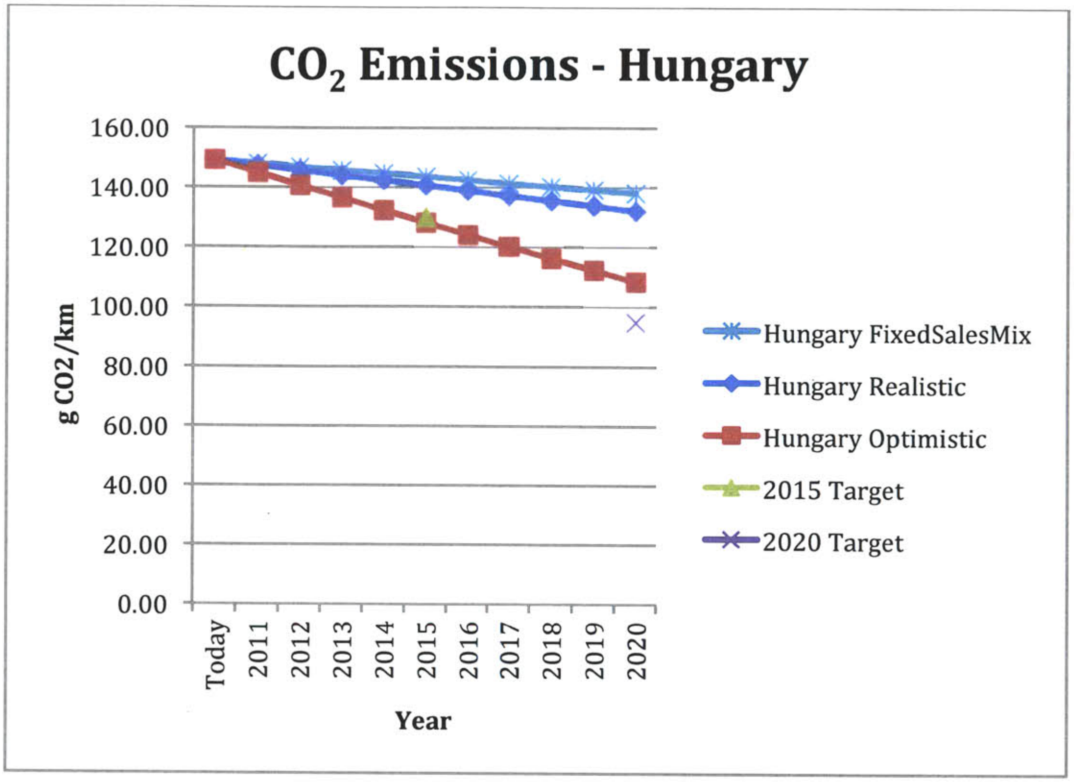

Fig. 4.8 Projected CO_2 Emissions - Hungary

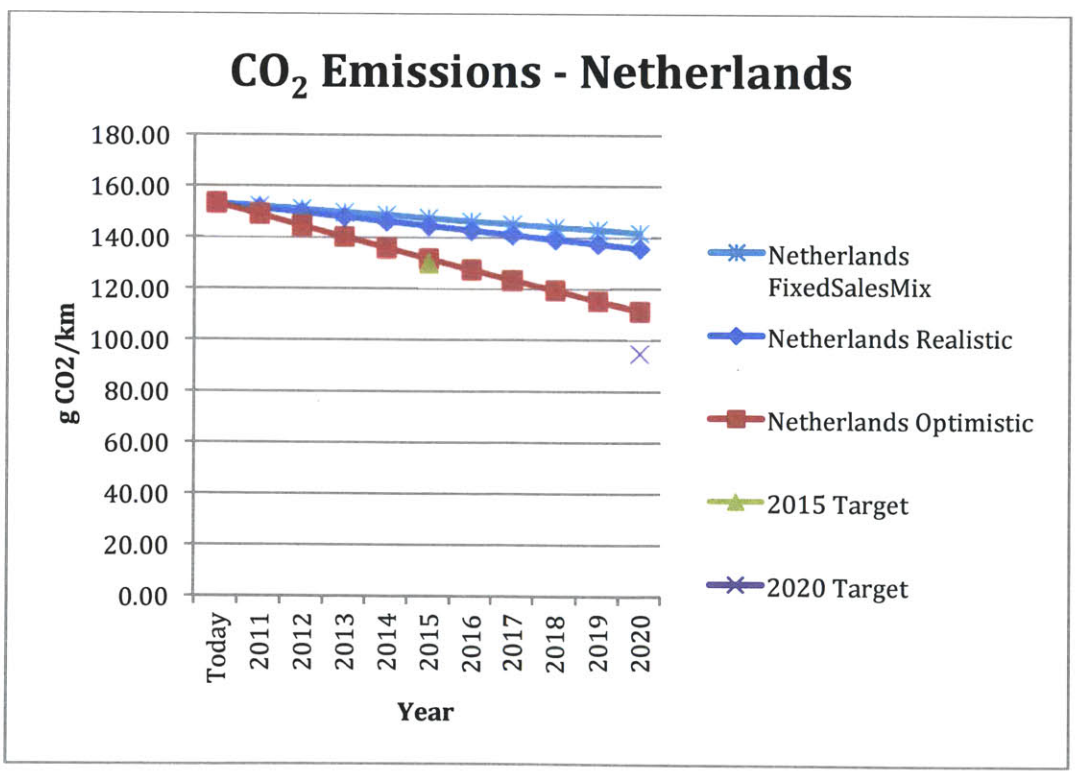

Fig. 4.9 Projected CO_2 Emissions - Netherlands

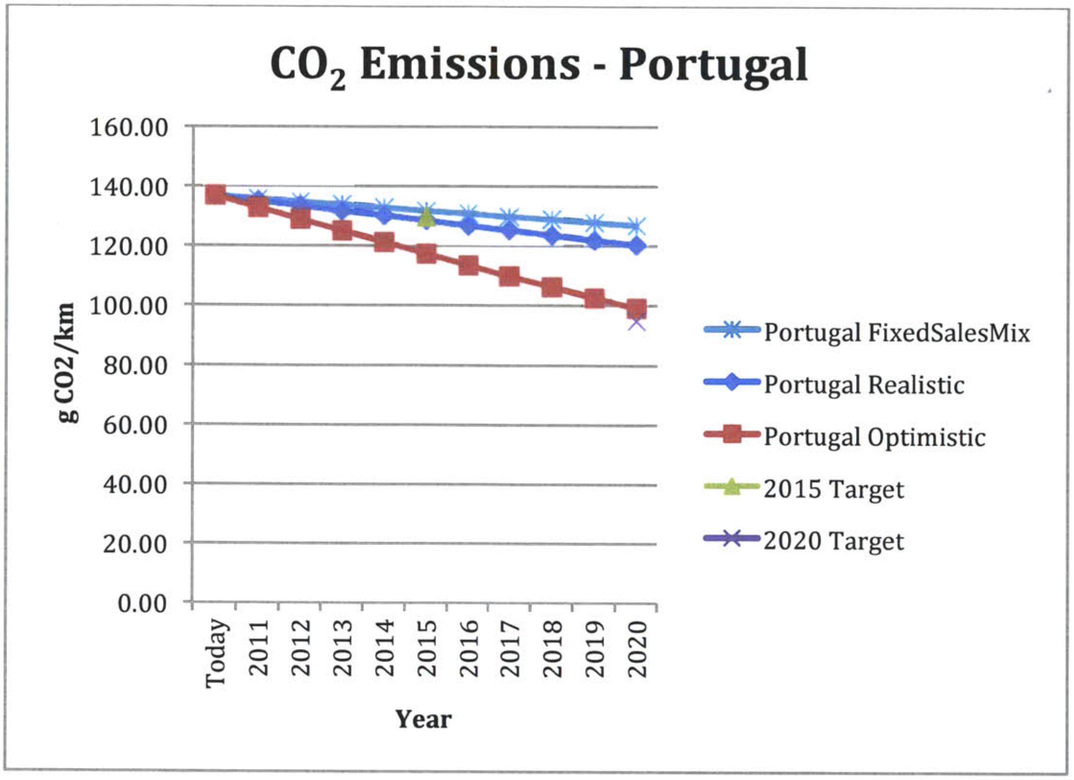

Fig 4.10 Projected CO_2 Emissions – Portugal

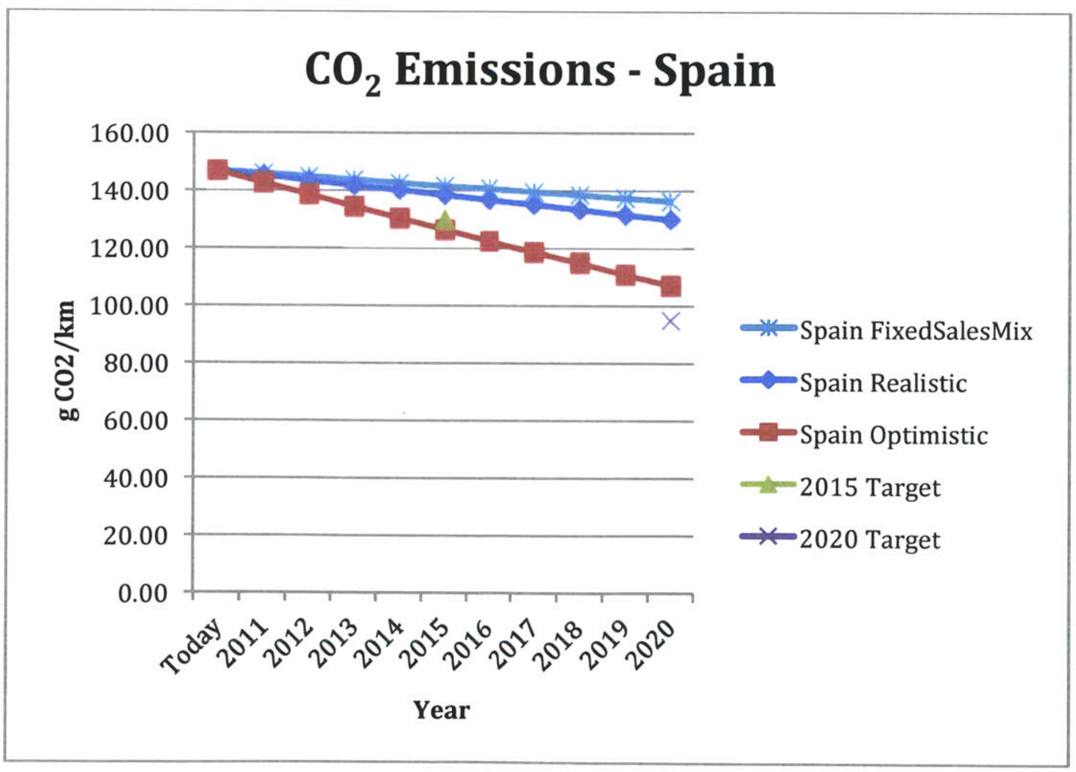

Fig. 4.11 Projected CO_2 Emissions - Spain

4.4 Feasibility For The Representative Europe

Figure 4.12 illustrates the projected CO_2 emissions for Europe as a whole, for all the three scenarios and for the period from Today to 2020.

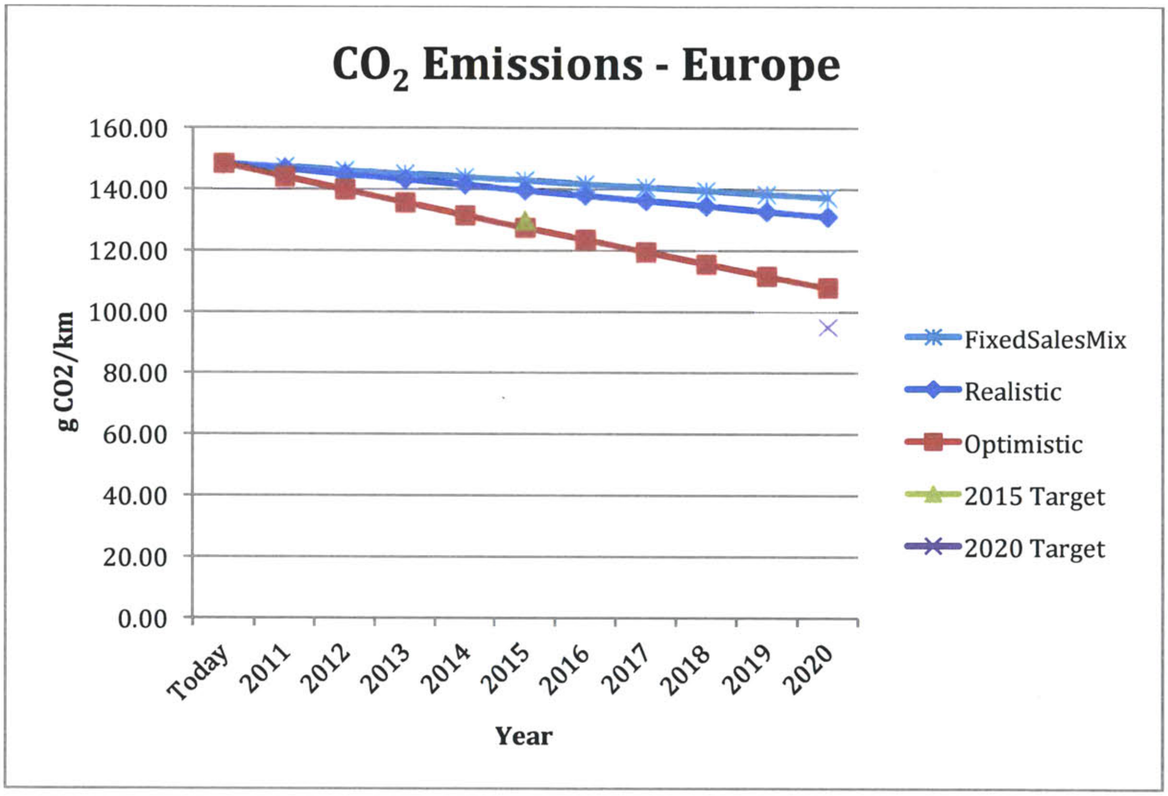

Fig. 4.12 Projected CO_2 Emissions – Europe

This result shows that as a whole the representative Europe that we have considered in this study could meet the 2015 target on time, in the optimistic scenario. This is important because the emissions will be monitored cumulatively over the whole EU in order to determine whether or not the 2015 target is met by a manufacturer. However, the 2020 target still remains elusive for the combined region.

4.5 Fuel Use Reduction Potential

In the Fuel Use Reduction Potential graphs below, the line labeled 'Reference' shows the Fuel Use trend corresponding to a scenario where the sales mix remains constant at Today's levels through the period under consideration. Further, the ERFC for the Reference case stays at 50% and there is no additional vehicle weight reduction assumed.

These graphs should be read by considering each wedge as representing the improvement achieved by introducing an additional option. For example, in Fig. 4.13, the blue wedge refers to the improvement achieved –over the Reference case- by increasing the ERFC from 50% to 75%. And the yellow wedge shows the improvement achieved –over the impact of the increased ERFC- by introducing gasoline turbocharged vehicles to the fullest extent by 2020. The rest of the wedges can be read similarly.

Figure 4.13 and 4.14 show the fuel use reduction potential for Germany in Optimistic and Realistic scenarios respectively.[15]

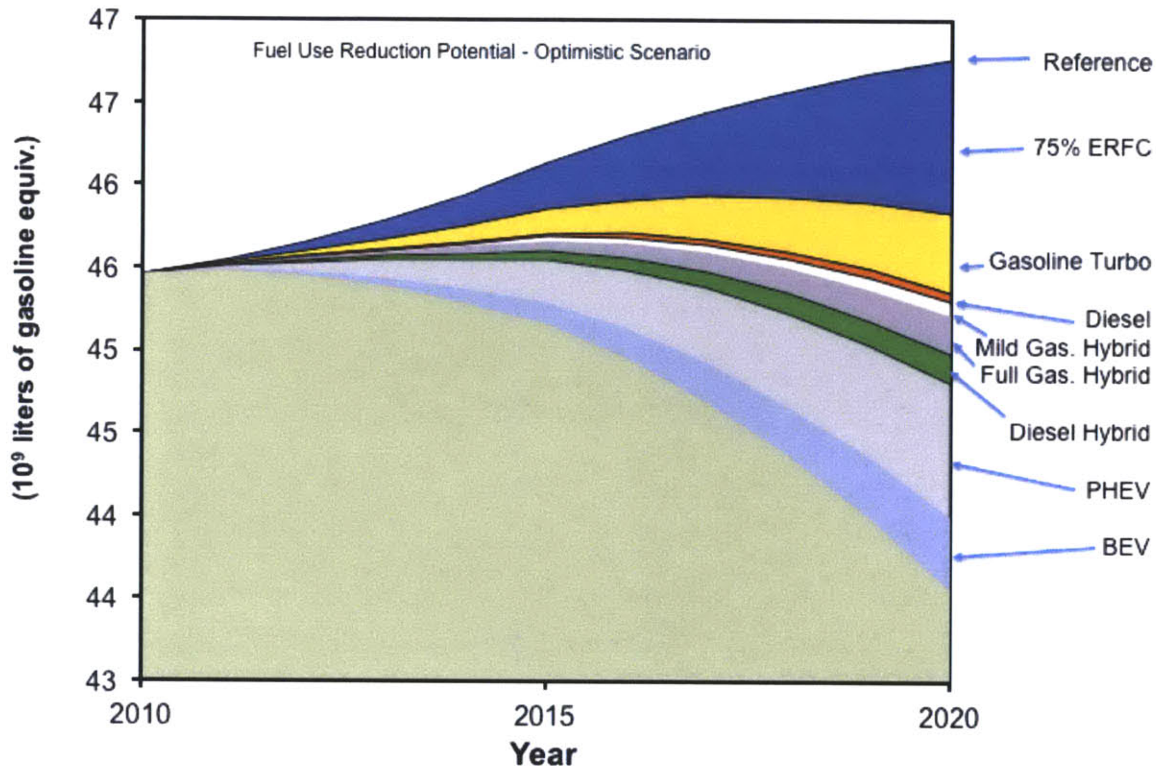

Fig. 4.13 Fuel Use Reduction Potential – Optimistic Scenario - Germany

[15] Note that the expanded vertical axis does not start from zero.

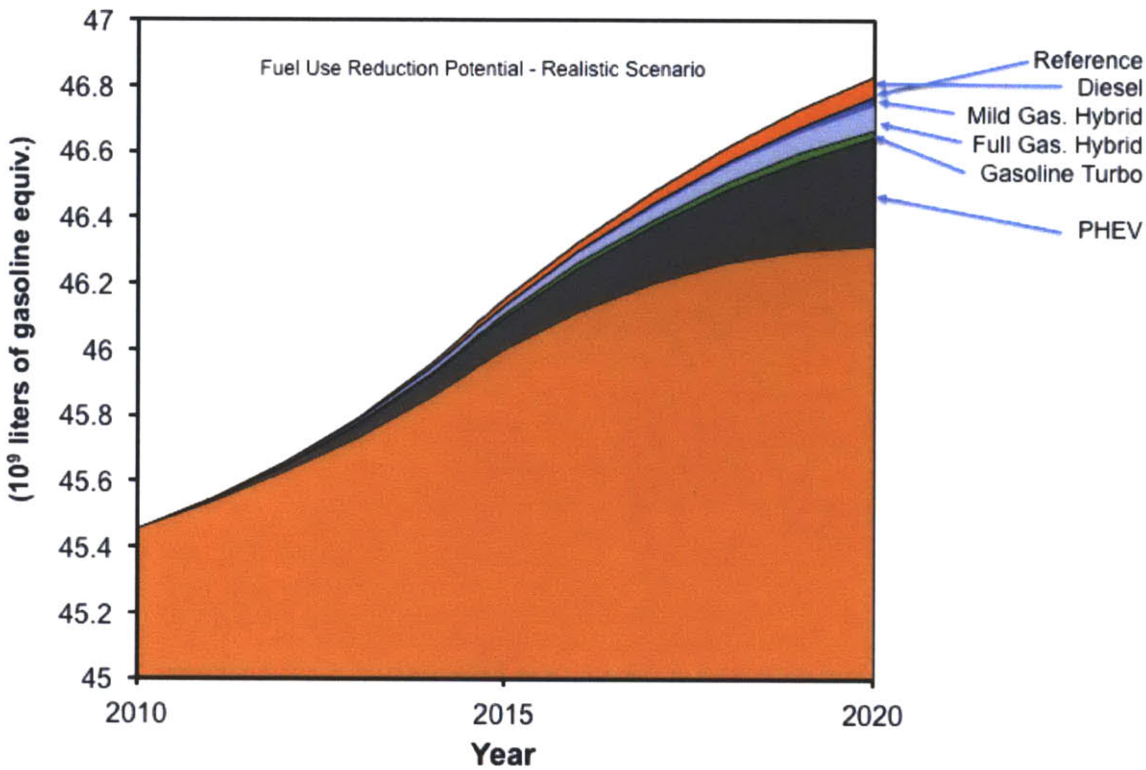

Fig 4.14 Fuel Use Reduction Potential – Realistic Scenario – Germany

It can be seen from Fig 4.13 that improving the ERFC from 50% to 75% has the most impact on reducing fuel use. Further, in both the scenarios, it can be seen that PHEVs have a very significant potential to reduce fuel use. The impact of increase in Diesel car share in new passenger car sales in the realistic scenario over the Reference scenario is visible in Fig 4.14 where the Diesel wedge lies above the Reference line. This projected fuel use increase due to higher sales of Diesel cars is consistent with the relatively higher VKT for Diesel cars when compared with Petrol cars.

Figures 4.15 and 4.16 show the fuel use reduction potential for France in both the scenarios.

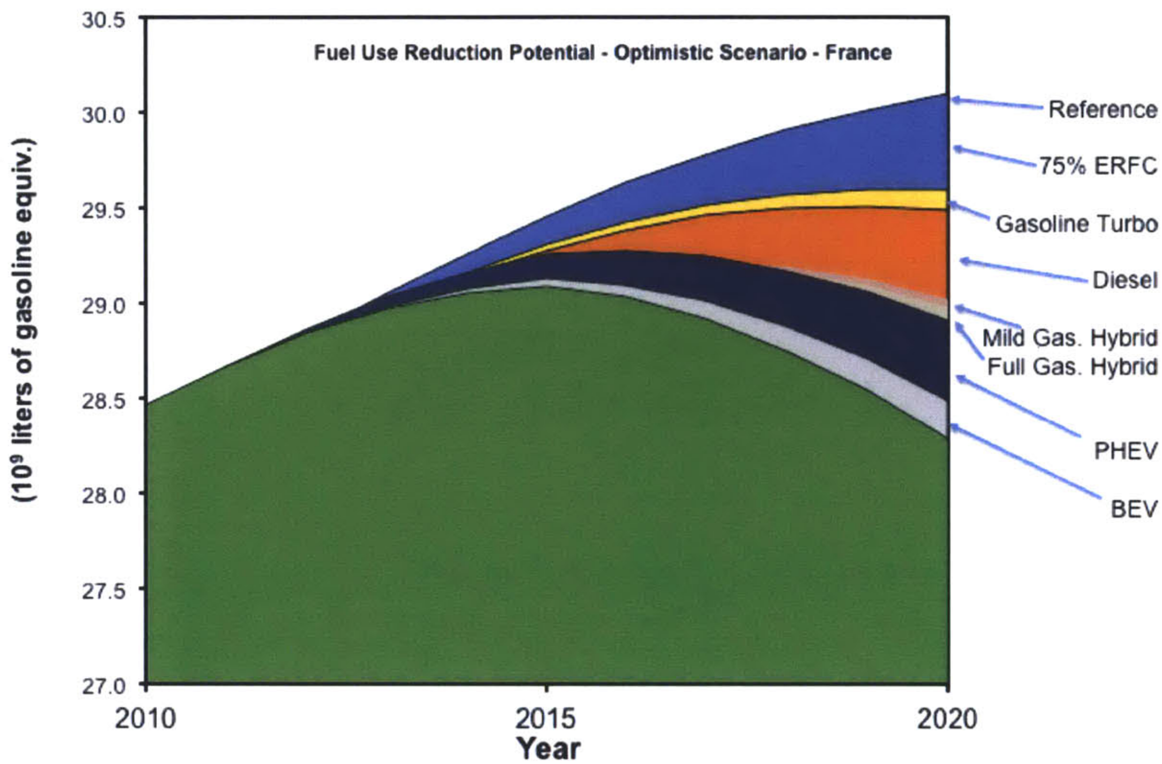

Fig. 4.15 Fuel Use Reduction Potential – Optimistic Scenario – France

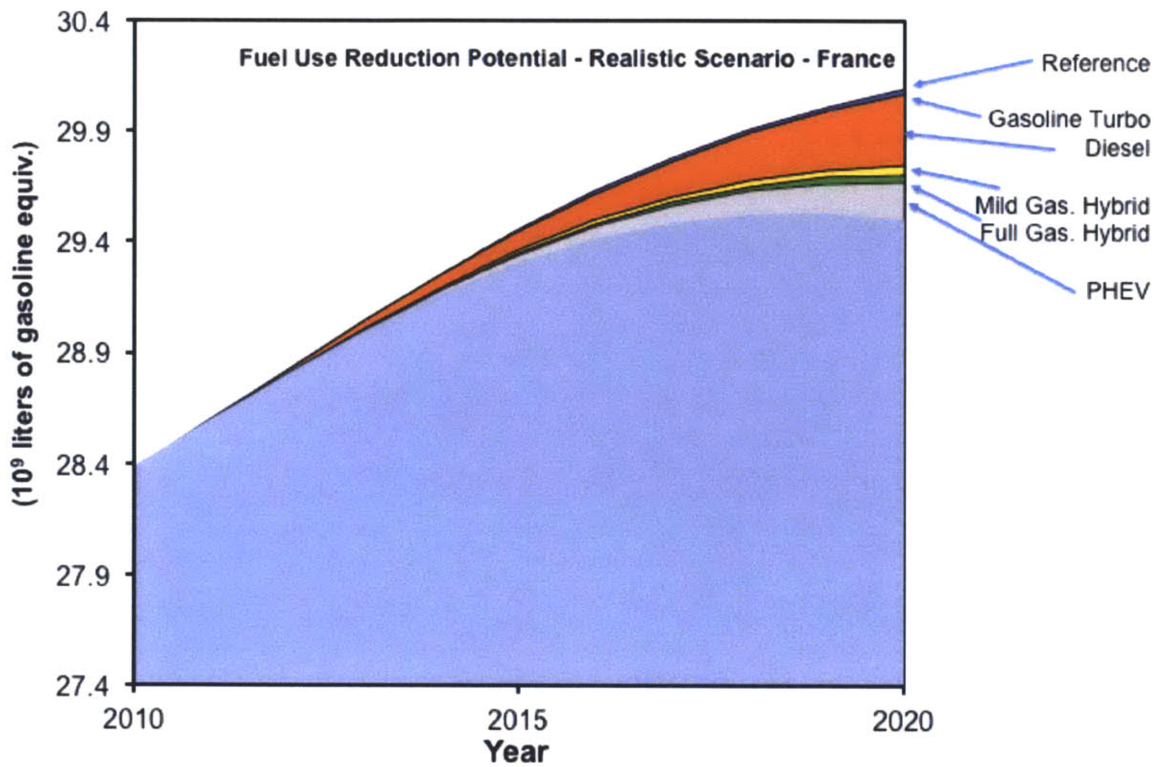

Fig 4.16 Fuel Use Reduction Potential – Realistic Scenario – France

While the impact of increase in ERFC and introduction of PHEVs is similar to that seen in the case of Germany, a significant point to be noted in the case of France is the reduction in fuel use due to Diesel share reduction in both Optimistic and Realistic scenarios. This makes sense because, as specified in Table 3.6, Diesel vehicles run longer distances (higher VKT) on average than their petrol counterparts. Hence, less diesels sold per year lead to lesser overall VKT and hence lower fuel use.

Figures 4.17 and 4.18 show the fuel use reduction potential for Italy in both the scenarios.

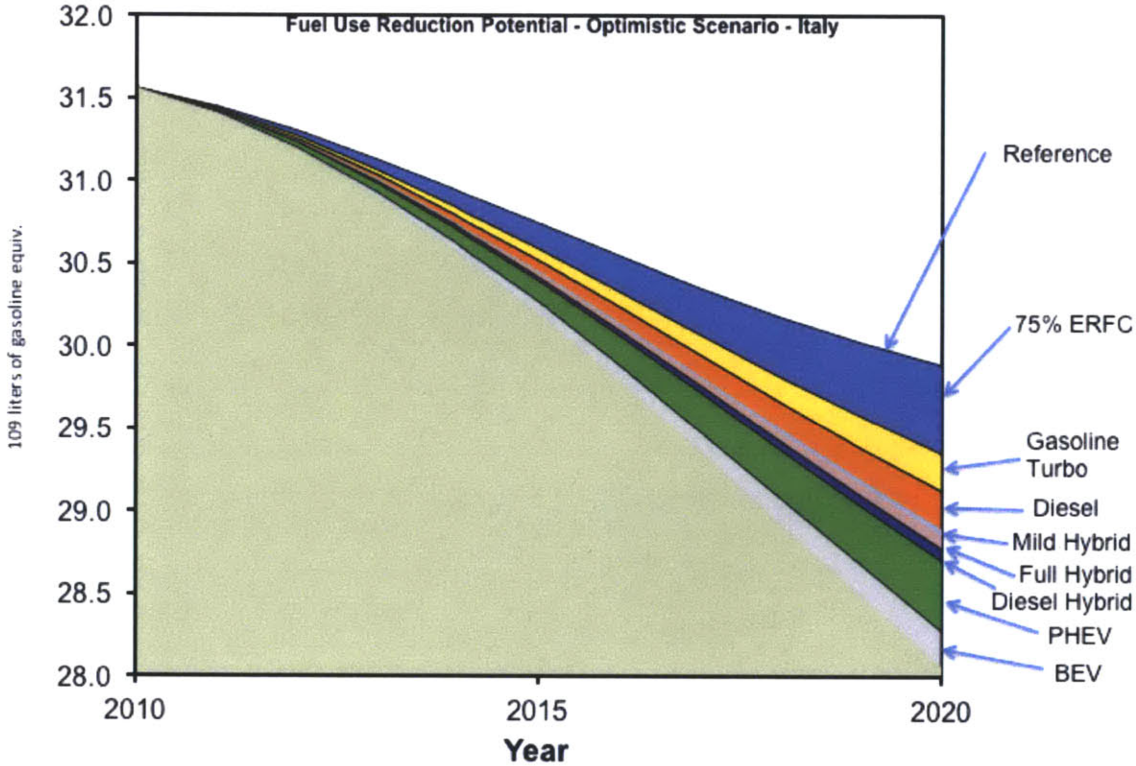

Fig. 4.17 Fuel Use Reduction Potential – Optimistic Scenario – Italy

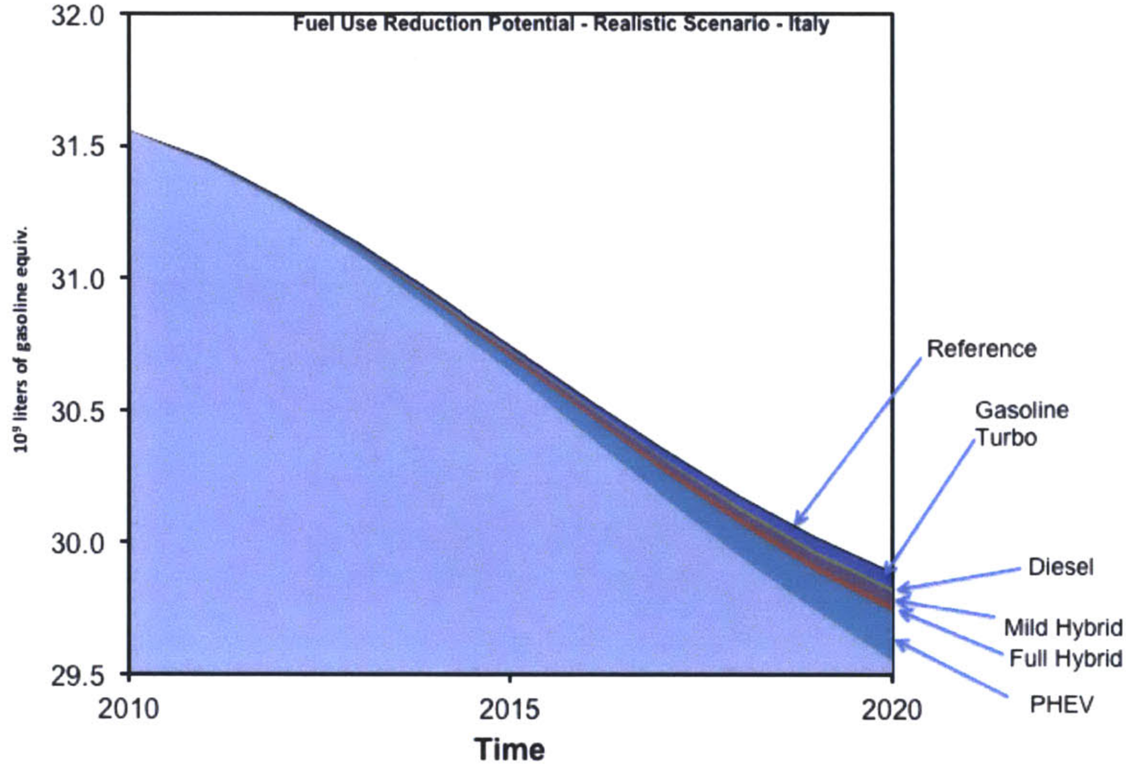

Fig. 4.18 Fuel Use Reduction Potential – Realistic Scenario – Italy

In the optimistic scenario, the reduction in diesel car share in new car sales results in an impact that is comparable to the impact of increase in turbocharger share. Further, increase in ERFC has a significant impact in fuel use reduction, as was seen in the case of other countries. Finally, introduction of PHEVs is seen to have a strong impact in both scenarios, especially in realistic.

Figures 4.19 and 4.20 show the fuel use reduction potential for UK in both the scenarios.

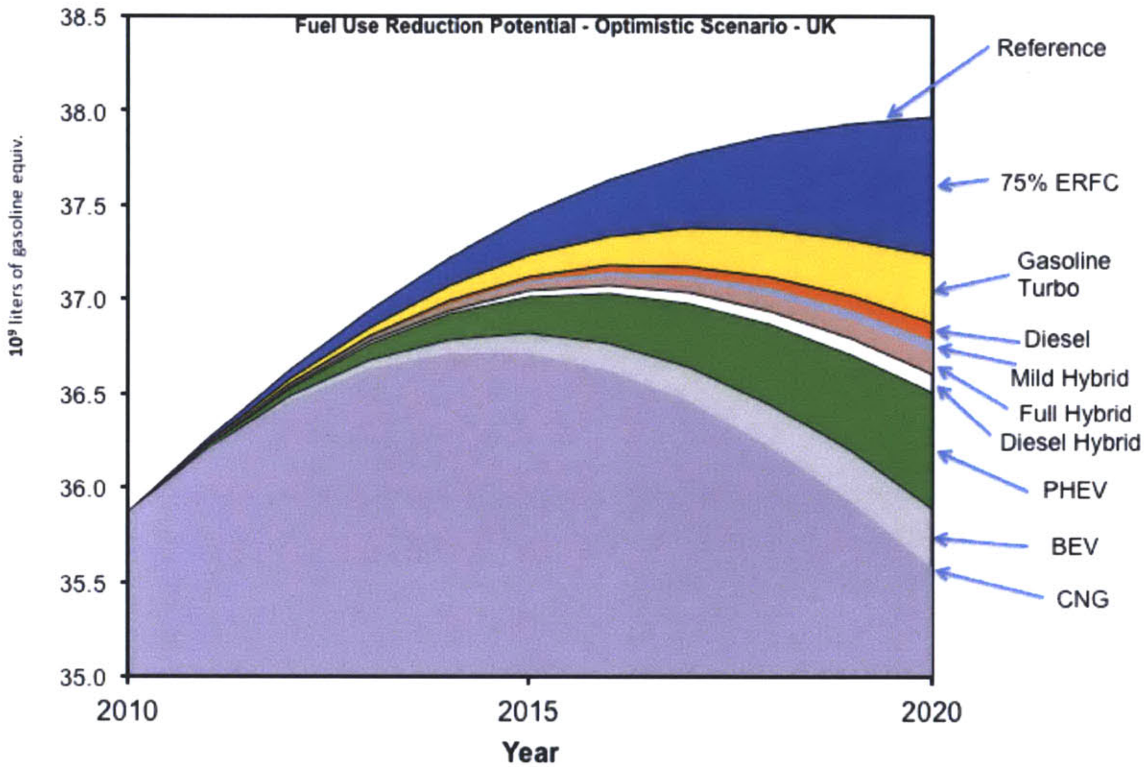

Fig. 4.19 Fuel Use Reduction Potential – Optimistic Scenario – UK

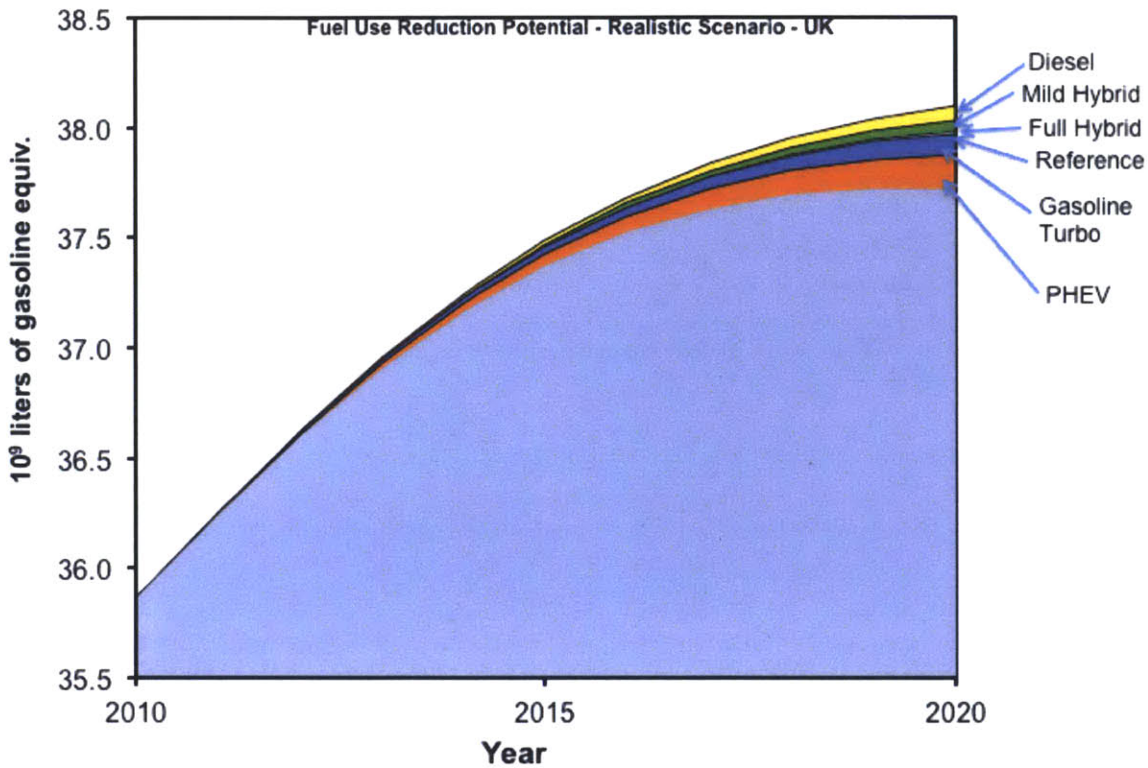

Fig. 4.20 Fuel Use Reduction Potential – Realistic Scenario - UK

The fuel use reduction potential graphs for UK are similar in nature to those of Germany. In the optimistic scenario, the most significant fuel use reduction happens due to increased ERFC, introduction of PHEVs, and increase in Turbocharger share. Whereas, in the realistic scenario, a higher Diesel share in new car sales leads to significantly higher fuel use as compared to the Reference scenario.

4.6 Diesel To Gasoline Fuel Ratio

The ratio of the demands for diesel and gasoline fuels is an important metric for European fuel refiners because they are concerned about the growing proportion of diesel demand. Figures 4.21 - 4.24 illustrate the evolution of this fuel use ratio for Germany, France, Italy, and UK, respectively, in the various scenarios.

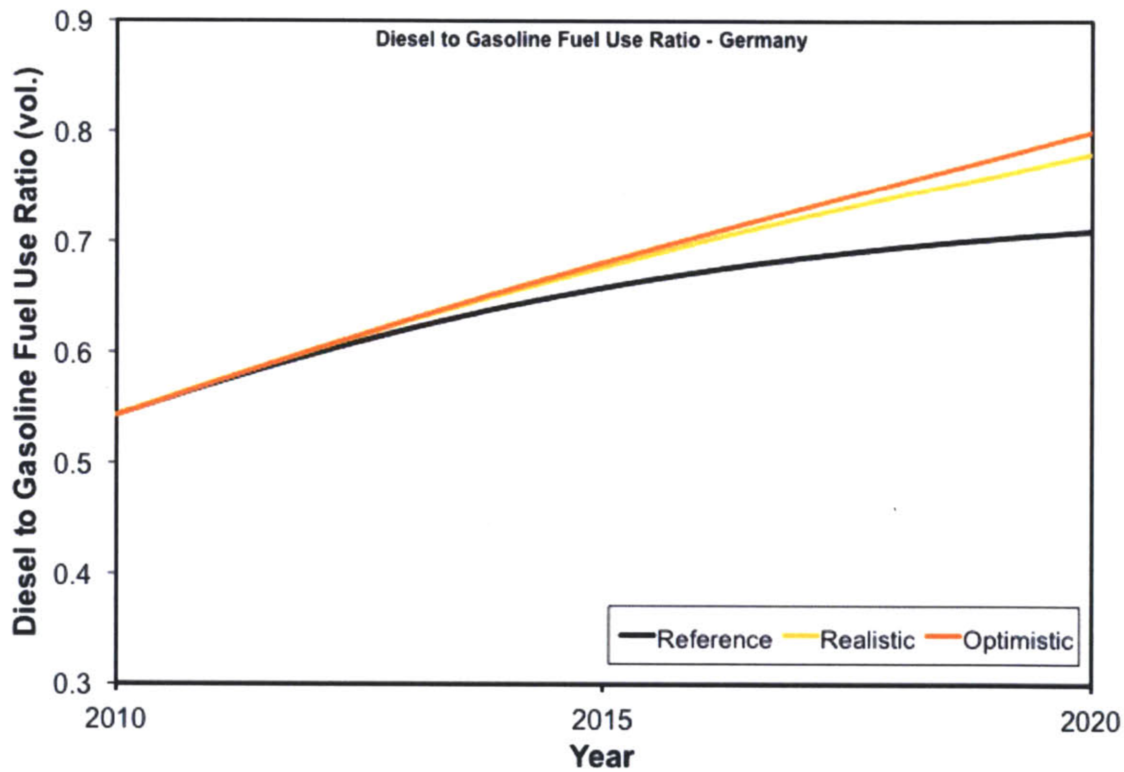

Fig. 4.21 Diesel to Gasoline Fuel Ratio - Germany

Fig. 4.21 shows that the diesel to gasoline ratio is set to increase from 0.54 to 0.71 (about 30% increase) in the Reference scenario, in Germany. Further, Optimistic scenario, which has the best chance to reduce CO_2 emissions, would lead to an even higher diesel to gasoline ratio, i.e. 0.8.

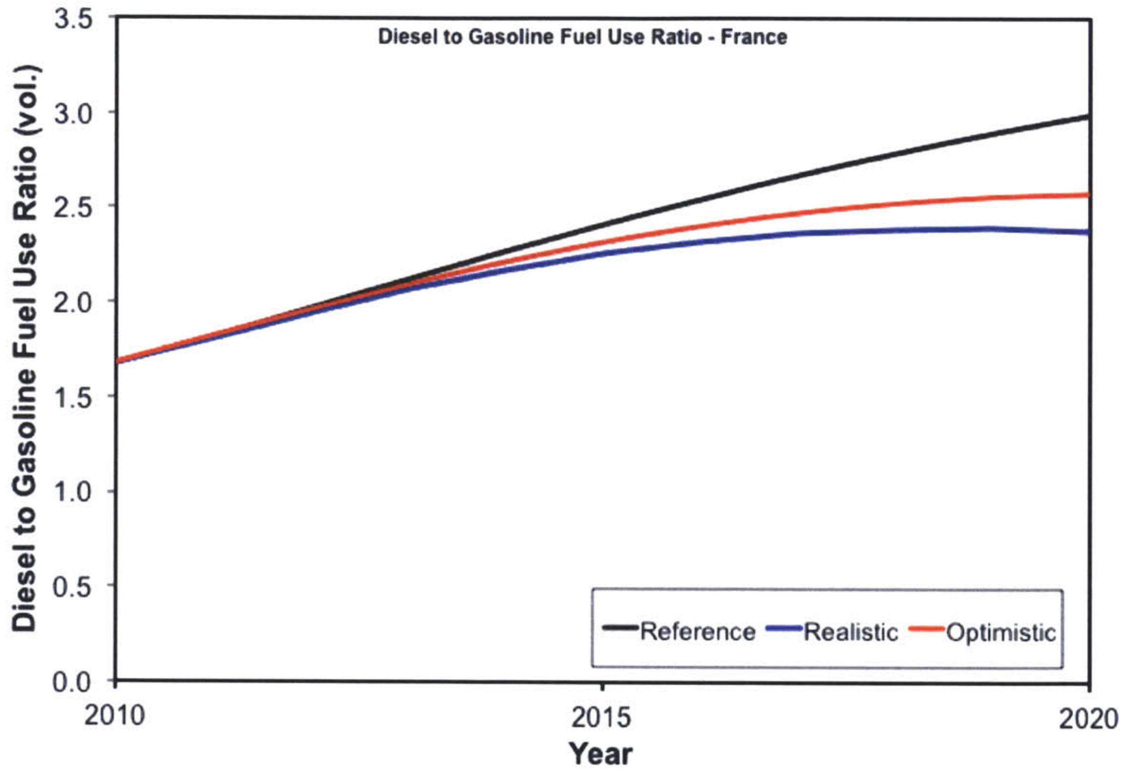

Fig 4.22 Diesel to Gasoline Fuel Ratio - France

In the case of France, the Reference scenario has the potential to increase the diesel to gasoline ratio by 80% over the current 1.67 to almost 3. The Optimistic scenario actually leads to a ratio of 2.58, which is roughly 14% lower than that in the Reference scenario and 54% higher than current value. And the Realistic scenario leads to a ratio of 2.38, which is 20% lower than that in the Reference scenario and 43% higher than today's value. Finally, it is important to note the significantly higher Today value of diesel to gasoline ratio in France when compared with the current and projected ratios in the other three countries.

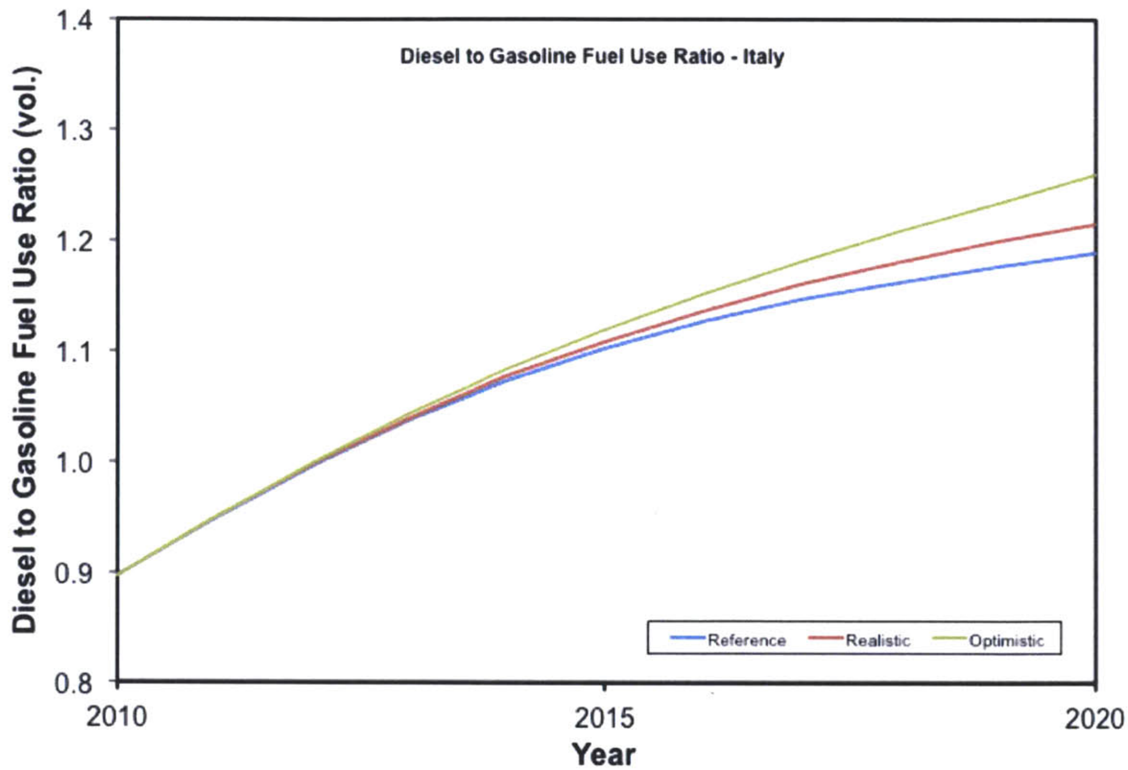

Fig. 4.23 Diesel to Gasoline Fuel Ratio – Italy

In Italy, the Reference scenario would lead to a diesel to gasoline ratio of 1.2 by 2020, an increase of 33% over the current value of 0.9. The Optimistic and Realistic scenarios lead to 2020 diesel to gasoline ratios that are barely 6% and 2% higher, respectively, than the 2020 ratio in the Reference scenario and 40% and 36% higher than Today's ratio.

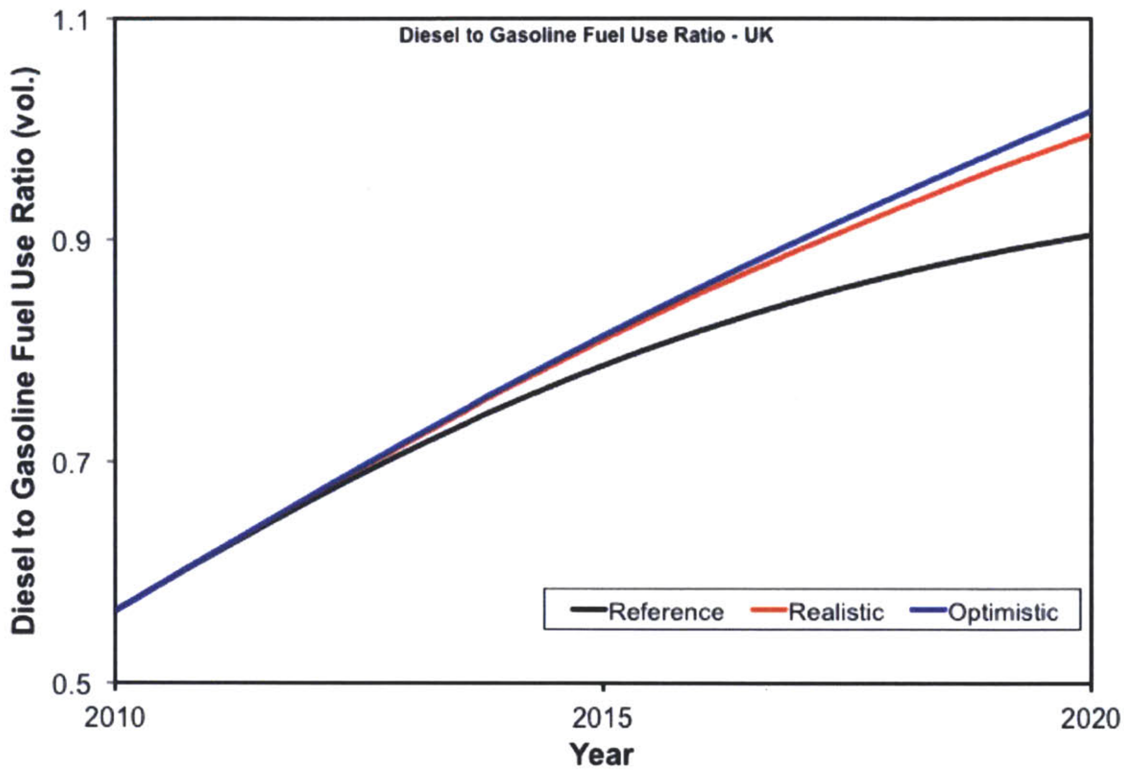

Fig. 4.24 Diesel to Gasoline Fuel Ratio – UK

In the Reference scenario in UK, the diesel to gasoline ratio would increase to 0.9 from the current value of 0.57, representing a 60% increase. Similarly, there would be a 76% and 80% increase over Today's value in Realistic and Optimistic scenarios to yield ratios of 1 and 1.02, respectively. These values would be 10% and 12% above the 2020 ratio for Reference scenario.

It is important to note that for all the countries the diesel to gasoline ratio increases partially on account of the gasoline technologies (NA-G, Turbcharged Gasoline, Mild and Full Gasoline Hybrids) improving more than the diesel technologies (diesel engine, diesel hybrid), on average. This factor further enhances the impact of rising diesel car fleet on the diesel to gasoline fuel use ratio.

5. Conclusions

5.1 Feasibility Of Achieving The 2015 And 2020 CO_2 Emissions Targets

This study suggests that Europe as a whole should be able to meet the 2015 target under the Optimistic scenario; however the 2020 target would be beyond reach under both the more optimistic and more realistic scenarios.

In the Optimistic scenario, all the nine countries analyzed would meet the 2015 target with a two-year delay. In the Realistic scenario, only two countries, France and Portugal, are able to meet the 2015 target; all other countries would face delays of at least 4 years.

None of the countries will be able to meet the 2020 target in either of these scenarios; only Portugal comes close to meeting this target under the Optimistic scenario.

5.2 Fuel Use Reduction Potential

The analysis shows that in France (a high diesel share country) the highest impact on fuel use reduction comes from reducing the number of new diesel cars sold because it is expected to reduce the mileage driven, in both the scenarios. New lower fuel using technologies like Turbo-gasoline/PHEV/EV could only come up at the expense of diesel cars, assuming a minimum level of demand for gasoline vehicles. Further, a lower number of diesel vehicles results in lower overall VKT, ultimately leading to lower fuel use in France. Moreover, PHEVs and BEVs also significantly help reduce fuel consumption.

On the other hand, in Germany and the UK, the biggest potential in reducing fuel use could come from enhancing ERFC and introducing PHEVs. While ERFC reduces the biggest individual portion of fuel used in Optimistic scenario, PHEV shows the best potential to reduce fuel use in Germany and the UK in both scenarios.

In Italy, the most significant fuel use reduction options beyond increased ERFC and introduction of PHEVs would be lowering of Diesel share in new car sales and increasing the Turbocharged Gasoline vehicles, in the optimistic scenario. In the realistic scenario, the biggest impact in fuel use reduction comes from introduction of PHEVs followed by the increase in Turbocharged Gasoline vehicles.

All in all, an increase in ERFC and introduction of PHEVs would most help reduce fuel use in all studied countries. In France and Italy, a reduction in Diesel car sales, accompanied by proliferation of PHEVs and BEVs, would additionally be significantly useful in reducing the fuel use due to lower overall VKT. Whereas, in Germany and UK, a higher number of Turbocharged Gasoline cars would be another significant option to reduce fuel use.

5.3 Diesel to Gasoline Fuel Ratio

The diesel to gasoline ratio will continue to increase for Germany, France, Italy and United Kingdom, in all scenarios. As described in the previous section, this is due partially to the increasing diesel fleet and partially to the relatively greater improvements on average in gasoline technologies (NA Gasoline, Turbocharged Gasoline, and Mild and Full Gasoline Hybrids) over the diesel technologies (Diesel, and Diesel Hybrids).

In Germany, United Kingdom, and Italy, any move towards reducing carbon emissions from cars would lead to an increase in the relative demand of diesel fuel. This is consistent with the fact that any new low emitting technologies will eat into gasoline share since diesel is likely to remain the fuel of relative choice because the (current) tax subsidies make it cheaper to own diesel cars. In France, however, the ratio will likely decrease if further attempts to reduce emissions are made. This makes sense since gasoline is already at a low level and any further new technology penetration will have to eat into diesel's share, given a certain minimum demand of gasoline vehicles.

Also, it can be seen that for both the countries, the diesel to gasoline ratio does not differ greatly under both the scenarios. This seems to follow from the relatively shorter –when compared to in-use vehicle lifespan- time span under consideration. Since the main difference between the two scenarios comes from new technology penetration, it stands to reason that it would take some time for vehicles with these technologies to replace the vehicles with older technologies, leading to lower divergence in fuel use ratios in the shorter term under both the scenarios.

Finally, it is also apparent that attempts to reduce emissions would lead to an equilibration of Diesel to Gasoline ratio in the countries taken together. Germany and United Kingdom stand to observe a high growth in diesel to gasoline ratio in both Optimistic and Realistic scenarios. Italy, which has a relatively higher diesel to gasoline ratio currently, seems on course to see relatively moderate gains in the ratio in both the scenarios. France, on the other end of the spectrum, has a very high current diesel to gasoline ratio and the ratio is likely to go down in both Realistic and Optimistic scenarios.

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