“Environmental Benefits and Economic Rationale of Expanding the Italian Natural Gas Private Car Fleet”

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1. Foreword

1.1 Context

On December 2003, the European Commission drew a plan about the deployment of alternative fuels in road transport. Natural gas, or CH_4 alternatively, played a major role in this non-binding report. Every single EU Country should have by 2020 a 10% share of natural gas-fuelled cars, passing through 2% in 2010 and 5% in 2015. Honestly, it seems like a challenging gamble since most EU Countries have an almost non-existent CH_4-fuelled fleet. Alternatively, Italy already has both a sizeable fleet and a good knowledge of how to use methane for automotive purposes. Consequently, it would be easier in the Italian context to attain this proposal.

At present, the Italian natural gas refueling network is growing at a fairly fast rate. There are already plans to build new stations, especially in the less-served geographical areas. This phase began in the 90's when environmental issues were extensively felt and influenced by public opinion.

1.2 Issue's importance

The advantages deriving from expanding the NG-fuelled car share are manifold. First of all, it will help to lower both the global and the local emissions. Since car fleet mileage has continued to grow, the present, already alarming, situation could become even harsher. There are many ways to fight this phenomenon: implementing car sharing and car pooling policies, supporting an extensive use of public transportation, to mention only a few. But widening the use of low harmful fuels would undoubtedly be one of the most effective way to tackle this problem.

Then, it would allow reduced dependency from oil derivatives. Diversifying fuel types would mean having the possibility to increase the security of supply. Recently this issue has gained importance because of the international political situation. Italy could decide to re-allocate its purchases of natural gas, favoring Countries that are considered more politically stable.

By supporting the development of this industry, new employment opportunities would be created. There would be the need to hire additional people in the filling stations, for example.

On top of that, new Research would be required to develop natural gas engine-related technologies. This would allow Italy to gain a competitive advantage in the future marketplace by managing this sort of knowledge. In the early stages in the industry, Italy was a pioneer in this market and now it has the opportunity to revitalize that role.

1.3 Final aim

The aim of the present work is to compare environmental beneficial effects and financial requirements of expanding the present Italian natural gas-fuelled fleet in Italy up to 2020. The intuition driving the researcher to implement this model is composite. What is the magnitude of investments required to build an appropriate refueling network? How much pollutant emissions can we save by supporting this fuel? Is the network capable of supplying this quantity of natural gas? Other, more qualitative, considerations should be taken into account. For instance, improved energy supply security has a substantial role in this issue. But since model is meant to be primarily quantitative, more attention will be paid to analyzing these aspects.

Ultimately, this work focuses on what are the implications of having a natural gas fleet. It is not meant to be stand alone research. Indeed, it is supposed to support Government decisions when called to choose the optimal “fuel portfolio” regarding private cars in the years to come. It aims, therefore, at shedding some light over one of the many technical solutions. After making the industry's situation clearer, the set of information will hopefully be more comprehensive, driving a more sound fuel policy.

1.4 Expected results

As already mentioned, the two main factors that will be taken into account will be the infrastructure costs and the avoided gaseous emissions. Infrastructure costs mean, in this context, building new refueling plants than the Business As Usual case and connecting them to the existing network. Regarding gaseous pollution, the issue will be divided into two main parts: global and local emissions. These quantitative results will have to be compared with the outcomes of similar research.

The researcher would expect to find that global emissions from natural gas-fuelled vehicles are lower but not enough to justify the additional investments. What really could drive the decision to support natural gas is the significantly lower local emissions. Quantifying this aspect would mean having a solid basis to assess if the additional costs are worth the initiative.

1.5 Possible way to exploit the data

The possible scenarios coming out of this paper are meant to be used by whomever is in charge of defining the fuel mix in the road transport sector. While assessing how to allocate the shares, one has to know exactly which are the quantitative effects deriving from all of the considered options. This work will sort out the main information regarding the natural gas option. In other words, it is supposed to provide a better knowledge to policy makers of which are the actual advantages and disadvantages of natural gas for automotive purposes.

2 The Italian context

The very early stages of CH_4 use in the transport industry in Italy were led by political reasons. The Fascist Government, forced by a Society of Nations embargo, issued a bill in the mid-30s compelling all private and pubic buses to be fuelled with CH_4 by January 1st, 1938. That, of course, boosted investments in both infrastructure and vehicle-related technologies making Italy a pioneer in this field[1]. Seventy years later we are still tackling energy security as a major issue. International players have changed, but the concern is the same and, admittedly, with stronger intensity.

Two other turn points made Italy rely more and more on this technology: the 1970's oil crises and a renewed and deeper environmental concern in the 1990's. That process seemed to slow down after WW2, regaining trust only as a feasible alternative to conventional fuels.

This long history of retrofitting gasoline-fuelled vehicles is confirmed by Italy's rank on an international basis. Having the forth biggest fleet, as of 2002[2], the infrastructure ranks fifth worldwide in terms of installed refueling plants. As of May 2005, Italian automotive CH_4 network consisted of 530 refueling plants[3] for private purposes. Though almost two thirds of them (330) are concentrated in only 5 out of 20 Italian Regions[4]. Even if these areas count as 39% of the total Italian population, this figure still remains remarkable.

The most recent projects for new plants tend to even this concentration, envisaging new constructions where the dearth is more evident (e.g. in the southern Regions). This would allow the network to have a more homogeneous reach for all end users.

When thinking of expanding the refueling network, other concerns remain. The first one is how to forecast the proportion of mono- and multi-fuel stations selling NG. Mono-fuel plants have more refueling modules but are more expensive since the main facility has to be built on purpose. Moreover, mono-fuel stations employees are better equipped to deal with compressed natural gas technology, being servicing a key factor in fostering the growth of CH_4 fuelled cars sales. The majority of the fleet is retrofitted by refueling stations-related garages and most of the repairs are done by them as well.

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[1] See Rinolfi and Cornetti (2004).
[2] Source: "The Gas Vehicles Report", February 2002.
[3] Source: www.federmetano.it.
[4] The five regions are: Lombardy, Venetia, Emilia-Romagna, Tuscany and Le Marche.

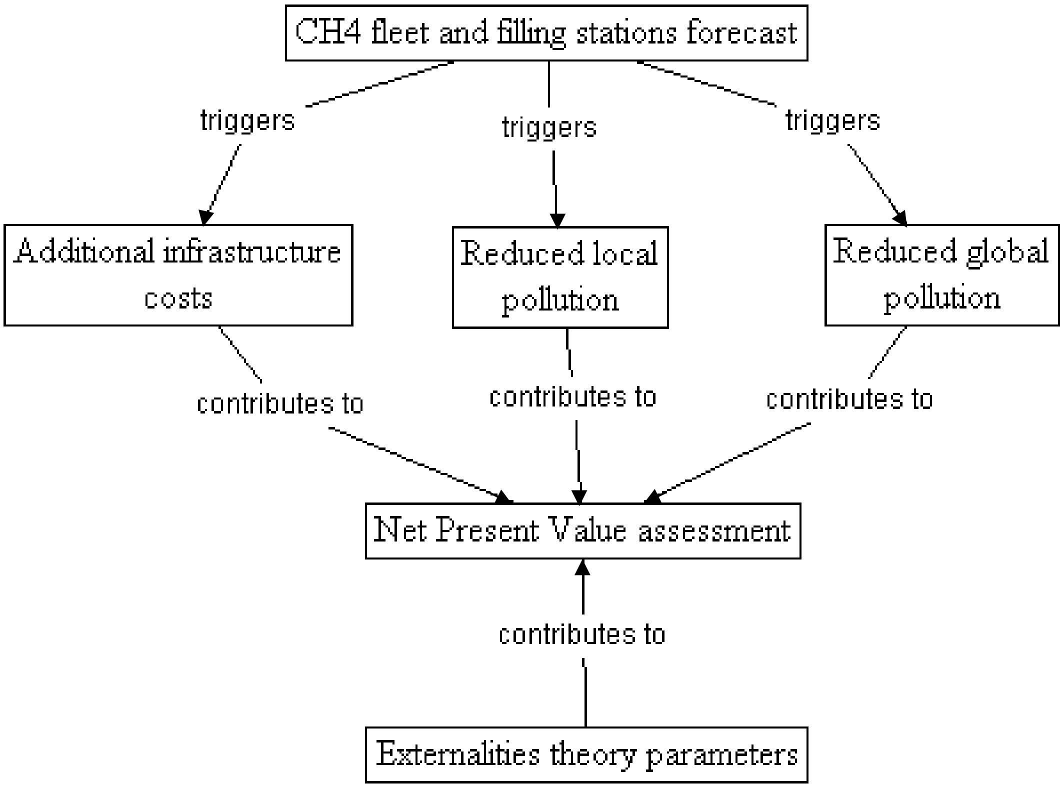
On the other hand, some gasoline stations can be modified, becoming multi-fuel. It is cheaper and it can rely on the existing infrastructure. Indeed, the optimal strategy would be to harness what's already in place, rather then building a parallel infrastructure. This holds particularly true for Italy, that outnumbers by far the average Europeans car/refueling plants ratio.

Secondly, a significant running cost is the power needed to pump methane up to the right pressure, i.e. about 220 bar. If the plant is located close to a town it's likely to have very low network pressure, requiring a need for more power. But filling stations closer to urban areas represent a better appeal on drivers. Conversely, outside the cities the so-called primary network would flow CH_4 at a close-to-desired pressure. This implies a lower use of energy but plants relatively out of reach for the majority of end users.

Last but not least, another factor that will strongly influence the infrastructure is the on-going liberalization. Indeed, in the past all CH_4 refueling plant owners were compelled to sign a contract with the by then monopolist, ENI. All contractors were granted the same conditions. This, for example, meant that no matter how big the annual CH_4 supply, there was a unique price for CH_4/cubic meter purchased. Now, instead, everybody can negotiate with whichever provider she/he might prefer, creating the potential to differentiate contract conditions (influenced mainly by bargaining power). This new element has added a source of uncertainty and, therefore, risk for those who are interested in starting up a new refueling plant. When asked to make a prediction of future costs in this sense, right now it's fairly challenging to answer. Hopefully, as time goes by liberalization will bring lower price levels for everybody, offsetting the abovementioned shortcoming.

3. The model "CH_4aCleanerAir"

The model "CH_4aCleanerAir" has a core part, named "CH_4 fleet and filling stations forecast", that envisages the future development of both natural gas-fuelled cars fleet and the related refueling plants network. It serves as an engine for all the other sections that, therefore, can be seen as its branches. Graph no. (1) shows how the abovementioned sections are combined together.

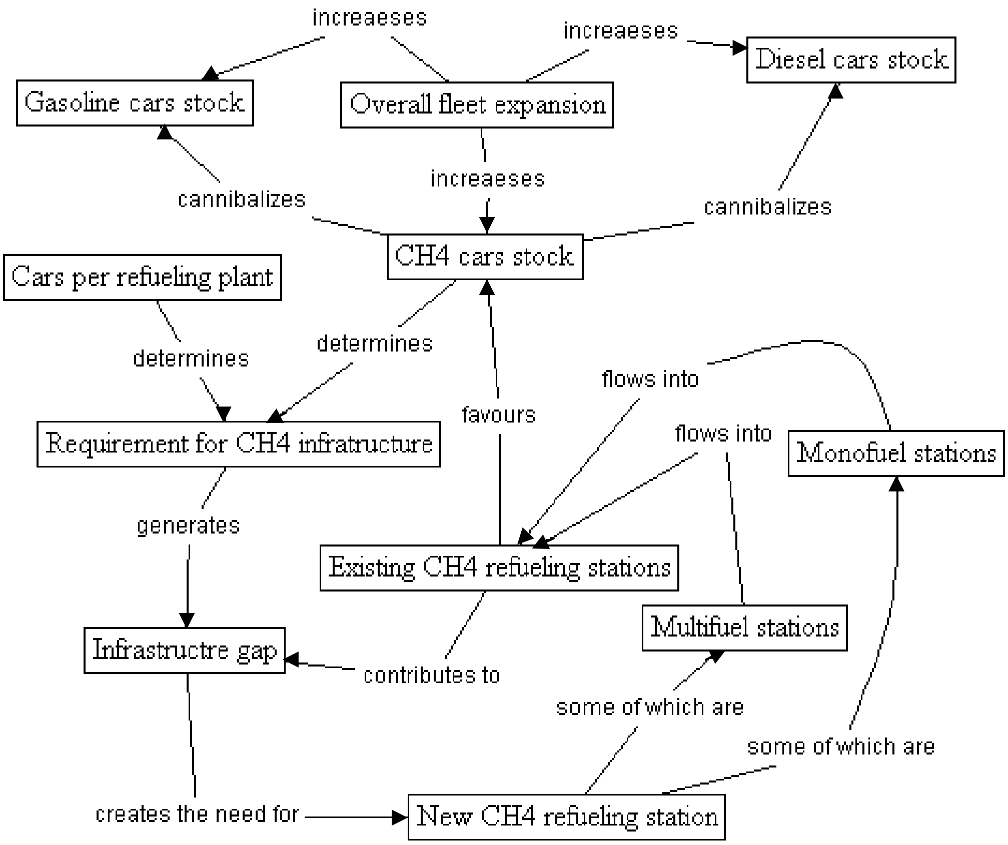


Graph no. (1): Model's core framework.

The original idea, as already mentioned, was to analyze effects on the various aspects involved in this transport option. For example, trying to compute the required refueling plant investments triggered by an hypothetical, strongly expanding methane-fuelled fleet. Likewise, it might be interesting to know how the present traditional fuel plants' infrastructure could back the expansion of automotive NG. Combining the previously mentioned data, a prediction regarding local and global avoided emission will be drawn.
The model foresees two scenarios: Business As Usual (BAU) and Scenario A. Intuitively, in the BAU scenario nothing changes from the present situation. This means, for instance, that the CH_4 fuelled car fleet will remain the same, as share of total, up to 2020. In scenario A, instead, some conditions will be changed. By modifying the underlying drivers of the model, the researcher would like to understand which are the leverages that could make natural gas an efficient solution for the automotive industry's development. Taken as given, the NG fleet forecast needs a plan that will maximize its positive effects, e.g. minimizing pollution. From time to time, single variables will be changed drawing hypothetical, but feasible, future states of the world.
These aspects are fully explained in the following paragraphs. Most of them are, from a quantitative point of view, treated separately, but each will jointly contribute to the final conclusion of this work.

3.1 The core section: “CH_4 fleet and filling stations forecast”

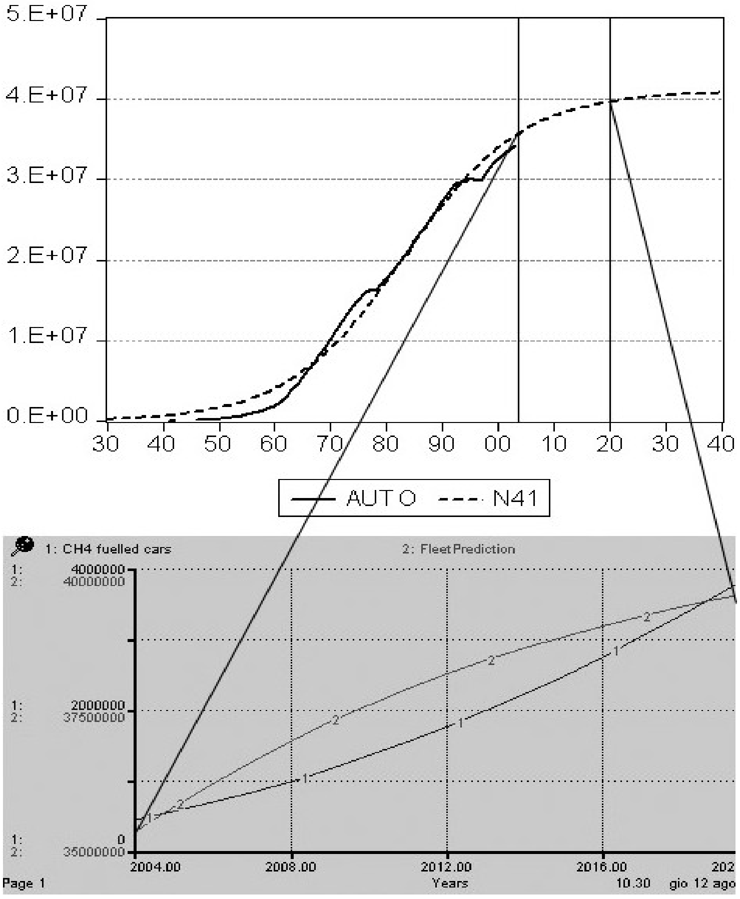
This part provides an up to 2020 forecast of the CH_4-fuelled cars fleet and the related number of required plants (both mono- and multi-fuel).
Combining “CH_4 cars stock” and the “Cars per refueling plant” variables gives the number of required plants (see graph no. (2) below). The underlying assumption, therefore, is to know this in advance and therefore resize the present infrastructure according to future needs and the construction time[5].



Graph no.(2): Main components of the fleet and plants forecast section.

The researcher takes into account only three fuels: gasoline, diesel and natural gas. This is justified by the fact that GPL fuelled vehicles play a minor role. In the future, likely, they will be taken over by the remaining fuels because the use of these cars is becoming relatively more expensive. Both electric and hydrogen fuelled vehicles pose serious problems when asked to draw a sound, quantitative forecast. They are not added because they would represent an additional source of uncertainty.
The prediction about the overall fleet up to 2020 originated by, an econometric regression. An S-shaped logistic curve fits the time series with different ceilings where to tend to (see graph no. (3) next page). At the end only five regressions’ parameters are considered (with 35, 38, 41, 44, 47 million cars as ceilings, respectively)[6]. This research wants to cover very different fleet evolutions in order to alternate them in Scenario A. 2004 Italian private car fleet consisted of 34,310,446 cars, 430,000 of which were natural gas-fuelled.

[5] Experts suggest to use an average year-long lag construction time.
[6] The R^2 of these regressions ranges from 99.3% (35M ceiling) to 97.9% (47M ceiling). A non-linear estimation of the logistic function parameters, β_0 and β_1, was carried out.



Graph no. (3): Upper part: "Auto" refers to the actual fleet data where N41 is the logistic regression (N because parameters were non-linearly estimated and 41 is the chosen ceiling). Lower part: number of NG-fuelled cars up to 2020 (1) and overall fleet forecast (2).

Natural gas-fuelled cars cannibalize both gasoline-fuelled cars and diesel-fuelled ones. But two facts make gasoline likelier to be replaced. First of all diesel car retail prices are becoming more and more competitive with gasoline fuelled cars. Then, diesel is still noticeably cheaper than gasoline in Italy. Therefore, an expansion of natural gas fuelled fleet will likely affect the relatively more expensive fuel of the two, i.e. gasoline.

On top of the economic line of reasoning, there are some technical aspects to consider. Cannibalizing can come through two ways. The first one is through the purchase of an Original Equipment Manufactured car. In other words the car is originally equipped to run on natural gas or on natural gas and gasoline. The second option is to buy an either gasoline or diesel fuelled car and then retrofit it. In this case retrofitting gasoline cars is much easier, and therefore cheaper, than modifying a diesel fuelled car.

Refueling plants in 2004 and 2005 are taken as given, locking the model in its first two steps. Whenever time *(t+1)* plants required exceeds time *(t)* existing plants, new plants by the same amount are automatically ordered for the year to come. Hence, "new CH_4 stations" is to smooth the forecasted additional time *(t+1)* need of plants. Intuitively, all "new CH_4 stations" are made to flow into the existing plants stock at the following period, when they actually become refueling plants. That is why if the required plants series monotonically goes up, the "existing CH_4 stations" series mimics the same pattern, lagged by one period of time (i.e., one year). Indeed, if the number of required plants stalled, there would be a perfect match between demand for infrastructure and existing filling plants.

The following formulae show how these concepts are expressed in algebraic terms[7]:

New CH_4 stations$_t$ = max [0,(Required stations$_{t+1}$-Existing CH_4 stations$_t$)] *(1)*
Existing CH_4 stations$_{t+1}$ = Existing CH_4 stations$_t$ + New CH_4 stations$_t$ *(2)*

The model is constrained not to allow a decrease in the stock of natural gas refueling stations[8]. This assumption is supported by the fact that a Government, after having spent so many efforts in expanding it, wouldn't allow the network to shrink. Moreover, common wisdom would suggest that it is not reasonable to decommission refueling plants while facing short term market fluctuations. If political power was to surrender to extemporary market fluctuations, it would give an impression of ambiguity about the way it leads the policy. In other words, Government has to be supportive of this initiative, even if there's a shrinking fleet, allowing the potential of a network to exist in any case. A non-negativity condition is, hence, set: if the number of required plants is below the level of existing ones, nothing happens.

During the simulations, the modeler can change the final CH_4 fuelled cars share and the final "cars per refueling plant" variable estimate. The latter was fine tuned according to suggestions collected by industry's experts[9].

Then, an important task is given to sorting out how many refueling stations would have to be either mono- or multi-fuel. This issue holds particular importance because of the different construction and running costs of the two[10].

Nonetheless multi-fuel plants are cheaper, the majority of the existing refueling stations are mono-fuel. This has been justified by the fact that who owns gasoline and diesel refueling stations has not been interested in modifying what he/she already has. Vice versa, so far it has been mainly the case that who wanted to start up a natural gas filling station had to do it without possessing a traditional refueling station. This way they had two options: either building a natural gas station or a station capable of providing all three fuels. The latter case is even more expensive than building a on-purpose natural gas station. That explains why mono-fuel stations have prevailed.

Everybody in the industry agrees that this trend will soon be reverted and that we will experience an increasing amount of multi-fuel stations. Consequently, the modeler draws a quadratic function between the present data and the assumed one, up to 2020. These shares determine how many mono-fuel and multi-fuel plants will be built each year.

The outcomes are two-fold regarding the number of refueling plants associated each year. They are used as a check variable for the stock of refueling plants and as a basis to compute the amount of investments required each year.

3.2 Infrastructure investments and running costs

Infrastructure investments mean expenditures related to the construction of new plants. Running costs, instead, are services or goods meant to be used within the year. They both refer to additional costs over the BAU scenario. Therefore, there is no surprise with regard to the existing infrastructure. This is justified by the fact that all the work is grounded on a single question: "what if we expanded the fleet and the refueling infrastructure?".

Investments required to build a multi-fuel rather than a mono-fuel refueling plant are different. Hence, average values of 125.000€ and 400.000€, respectively, are assumed. They could vary, for example, with the distance from the network[11]. Though, it is extremely

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[7] The variable "Required stations" is just the quantification of "Requirements for CH_4 infrastructure" as from graph no. (2).

[8] For example, tearing them down or even closing them temporarily.

[9] Mr. Mariani, from Metauto, and Mr. Tozzoli, from Federmetano.

[10] Multi-fuel refuelling stations range between 100.000 and 150.000 €. Multi-fuel stations range between 300.000 and 600.000 €.

[11] Connections costs are about 300-600€ per meter. They were included in the overall construction costs.

difficult to determine the distribution of this random variable. Most likely, the majority of new refueling plants will be built close to urban areas. This would mean they would be closer, in average, to CH_4 pipelines and, likely, need lower connection costs. But it still remains an ambiguous consideration to fit in a quantitative model like this. It is nevertheless worth mentioning because it will drive costs in any case, even if it's not easy to compute.
The latter fact has an influence on running costs. The closer to towns, the likelier there will be a secondary, lower pressure CH_4 network close by. This significantly affects the power required to compress the gas to the desired pressure. There is, thus, a trade off regarding the distance from urban areas between connection costs and the power bill.
Yearly power bills are the result of three factors: cost of power per kwh employed, energy required to deliver a cubic meter of CH_4 and the average cubic meter sales per year. The first figure is estimated to be 2 Eurocents per kwh. Then, on the one hand, energy required to pump the methane (as estimated by Mr. Mariani) is approximately 0.1-0.15 kwh/cubic meter of CH_4. Other estimates claim 0.1-0.35 kwh/cubic meter of CH_4 range as realistic. 0.15 kwh/cubic meter of CH_4 is taken as representative. Finally, average cubic meter sales per year is the result of total CH_4 used for automotive purposes divided by the number of plants for each year.
Other costs are also taken into account. Regarding labor, the researcher assumes that both types of plants need two employees to work. On average, the per employee annual cost for this kind of labor is estimated to be 25.000€/year, all inclusive.
The third cost included in the estimates is maintenance that, in 2004, is approximately 10.000€/year.
A basic assumption on inflation is made in order to express values in their real terms. An average 2% per year is, therefore, included. This hypothesis makes sense when thinking about the constraints posed by the European Central Bank concerning monetary policy.

3.3 Global emissions

Global emissions here are considered to deal only with CO_2 and therefore calculations are straightforward. In order to work out the total amount of CO_2 emitted per year, two sets of data are needed: the overall number of the fleets, sorted by fuel, and the CO_2 emission per car per kilometer. One can not weigh emissions by each individual fuel because these data are expressed in terms of kilometer traveled and the yearly mileages vary among the fleet. That's why weights are used in term of kilometer traveled by the single fleet.
Then the BAU scenario estimates are carried out, checking their consistency with real data. Subtracting tons of avoided CO_2 in scenario A from total BAU emission gives scenario A emissions. In order to make it in relative terms as well, global emissions reduction are related to total BAU global emissions. This gives us the extent to which policy can help to reduce pollution.
The percentage reduction of CO_2 from CH_4 compared to gasoline was meant to be in well-to-wheel terms (Life Cycle Assessment, LCA). A 25% LCA CO_2 reduction estimate was taken from the "Market development for alternative fuels" report by Alternative Fuels Contact Group presented to the European Commission on December 2003.

3.4 Local emissions

The major advantage of curbing local emissions would arise concentrating the CH_4 expansion in the most congested areas. Unfortunately, with this model it is not possible to tell where the expansion will actually take place. Therefore, the analysis is focused on a national level no matter the fact some cities or Regions would benefit more than others from this policy.
At any rate, the geographical distribution of the local pollutants was not among the objectives of this work. The aim, indeed, is to estimate the total avoided pollution in order to have a translation in monetary terms.
According to that, percentage reductions of pollutants in the expansion scenario are needed. The calculation is straightforward: reductions given by cannibalization (natural gas *versus* gasoline and natural gas *versus* diesel) are known. Following table no. (1) shows them all.

	% CO	*% HC*	*% NO_X*	*% Soot*	*% O_3*
NG vs Gasoline	-75	-82	-72	0	-88
NG vs Diesel	+38	-40	-95	-100	-50

Table no. (1): Natural gas-fueled vehicles local emissions compared to gasoline- and diesel-fueled vehicles. Source: FederMetano, www.federmetano.it.

The polluting contribution of each fleet is weighted by the fleet's mileage per year[12]. In other words, weighted average reductions of pollutants are computed to derive natural gas-fueled cars impact on the total fleet emissions.

3.5 Externalities estimate and Net Present Value

An interesting comparison would be the one between the actual costs incurred from expanding fleet and the monetary evaluation of avoided pollution. These considerations give a glimpse of how they could balance off each other.
The additional costs taken into account are those related to the infrastructure implying the construction of new filling plants. Running costs are also computed but not considered because the focus of the issue and the subsequent policy is long term. As a result, knowing the cash flow, related to this aspect, is meant only to provide additional information.
Beneficial effects need to be quantified with a comprehensive measurement. It sounds reasonable to use tools belonging to the externalities literature[13]. These, indeed, would embed both local and global emissions impacts on both the environment and human health.
Ultimately, NPV will turn out to be useful when comparing the cash flows of interest. The absolute values do not have an own meaning. They are only aimed at understanding if there is an off chance that natural gas might be successfully harnessed as an alternative fuel in road transport.

[12] Fleet X's yearly mileage = (fleet X's number of cars)*(fleet X's yearly average mileage).
[13] Data from Carslaw et al. (1995) quoted in a IANGV report were employed (and adjusted for inflation). They refer to the UK transport system, but since there were not similar data for Italy, the modeller would rather take these as an approximation.

4. Results

All the simulations are driven by a tentatively pre-set 2020 share of CH_4 cars (on the overall fleet). Gaps between the tentative one and the actual one have a twofold explanation. First of all the model foresees constraints regarding CH_4 network's growth for infrastructure-related reasons[14]. Then, cannibalization of natural gas *versus* other fuels rate is constrained, too. For example, aiming at 25% of CH_4 cars, only 21% is feasible, given the above mentioned constraints.

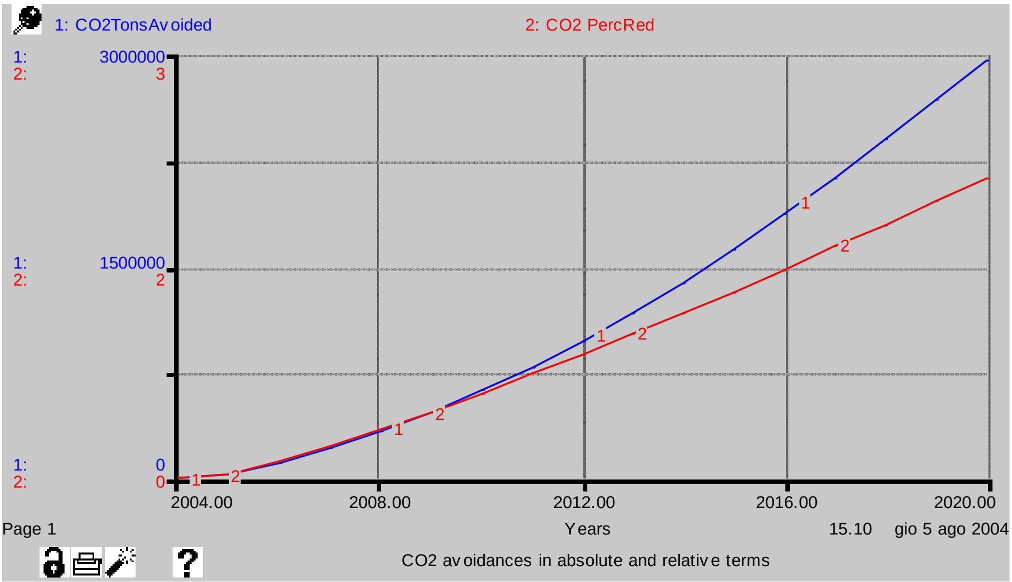
Only a median scenario is taken as reference for the discussion of the results. This scenario assumes 10% of cars to be fuelled by natural gas by 2020. Indeed, it is the same share suggested by the European Commission as previously mentioned in the foreword. By doing so it is possible to compare the results of this model with the ones of the EC report.

For instance, the final share of CH_4 filling stations from the simulation was approximately 18% compared to a 25% estimate by the EC. Another important indicator is the share of natural gas demand for automotive purposes over total demand of natural gas. That is consistent, too: EC estimate lies at 5% while this model suggest 6.3%. This rough comparison should prove the soundness of the 10% assumption.

The analysis and commenting of the results follow the structure of the model. Hence, a first look is given to global and local emissions reductions. On the "disadvantages" side, then, there is the quantification of investments required to build a proper infrastructure. These considerations jointly lead to a closing comparison within the Externalities theory framework.

4.1 Global emissions

CO_2 emissions avoided are very close to what one can expect. The ending figure is 2,37% decrease in scenario A than in the BAU scenario (see the path over the time span in graph no. 4, below).



Graph no. (4): CO_2 avoidances in absolute and relative terms.

Intuitively, if the share of NG-fuelled cars is 10% by 2020 and the LCA global emissions has been 25% lower than gasoline, a 2,5% decrease would be reasonable, other things being equal. The reason why it is 0,13% lower than a rough computation is because NGVs[15] usually

[14] E.g. availability to connect to natural gas pipeline network.

[15] Natural Gas Vehicles.

have lower mileage than diesel-fuelled cars (as assumed). Then NGVs total mileage share is lower then NGVs share[16].
Speaking about absolute terms, instead, an almost 3 millions tons of CO_2 could be avoided by 2020. The problem of dealing with CO_2 from the Transport industry, and in particular with road transport, is that this has been the industry with the fastest growth rates lately among the energy intensive ones. Technological innovations or developments, such this one, seem to have a hard time offsetting the growth.
Nonetheless, NGVs can only play a part in the wider policy of global emissions reduction in Transport. Since the policy will be about a portfolio of solutions to implement, one should consider whether NGVs are an efficient solution, from a monetary point of view. There's no doubt about the positive effects that might come from introducing this sort of policy. The problem lies on deciding how to allocate investments. There might be other ways to reduce CO_2 that are equally good or even better. This would lead to decide, for instance, to not have a 10% target but lower or higher, depending on the efficiency of the solution. But this decision has to be made after having assessed all the aspects related to this issue. The second of which is local pollution, following in the next paragraph.

4.2 Local emissions

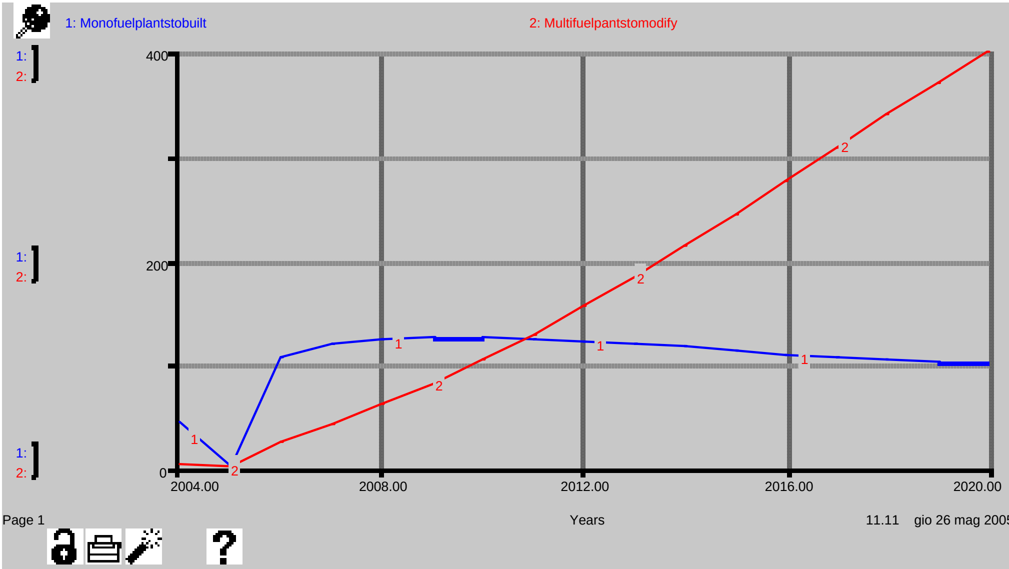
Given the already mentioned powerful potential of curbing local pollution, results of this section respond accordingly to expectations. Though, the simulation suggests that, depending on whether either gasoline or diesel are more cannibalized, different improvements in the air quality might occur. The model implies a dynamic by which natural gas-fuelled cars sales cannibalize mainly gasoline-fuelled cars sales. The following figure always refer to the end of the time horizon adopted, i.e. 2020.
On the one hand, abatement rates of CO, HC and O_3 are, respectively: 12%, 11.9% and 13.7%. Even if these seem small figures, it would be a good opportunity to diminish the pollution concentration in the most congested urban areas. Another straightforward conclusion is that either by elevating CH_4 share by 2020 or later than that, proportional reductions would come.
On the other hand, soot and NO_X effect is weaker. These two are finally lowered by 2.6% and 3.7%, correspondingly. Their major contributor is the diesel-fuelled fleet. In fact, the total amount of these pollutants is caused mainly by the deployment of diesel. On top of that, the increasing share of diesel-fueled cars will strengthen this relationship. Consequently, it will be more and more difficult to dent the vastness of these emissions. Alternatively, by forcing the marketplace to substitute more diesel-fueled cars with natural gas-fueled ones, one would have a better perspective regarding these pollutants. But, at the same time, a worsen situation about CO, HC and O_3.
These assertions lead to an obvious conclusion: substituting either gasoline or diesel, there is a trade off among the local gaseous pollutants to diminish. By taking over gasoline cars, the advantage would be in lowering CO, HC and O_3 emissions. By substituting diesel cars, instead, major reductions would be in soot and NO_X flows. A more balanced mix of cars to substitute would create a smoother reduction, among the pollutants, that would involve all local pollutants.

4.3 Infrastructure investments

The infrastructure dynamic for the first two years is not modeled but, instead, taken as given. In fact, by taking into account the ongoing filling station-related projects, quantifying the number refueling plants in 2004 and 2005 is straightforward. While bound for those years, from 2006 variables interact according to the modeled dynamic.
The ratio "car per filling plant" slowly and monotonically decreases over the years, starting from approximately 1,000. Meanwhile, natural gas-fueled fleet is growing slowly. Vice versa,

[16] I.e., less than 10% in this case. Polluting contribution is weighted by sub-fleet (diesel-, gasoline- and natural gas-fuelled) yearly mileage.

the number of filling plants to be finished by 2005 is considerable. This creates an "extra supply" of filling plants in the year 2005. As a result, the model suggests that no new projects are requested for 2006. As can be seen in graph no. (5) (below) there are no investments in 2005 for the following year.

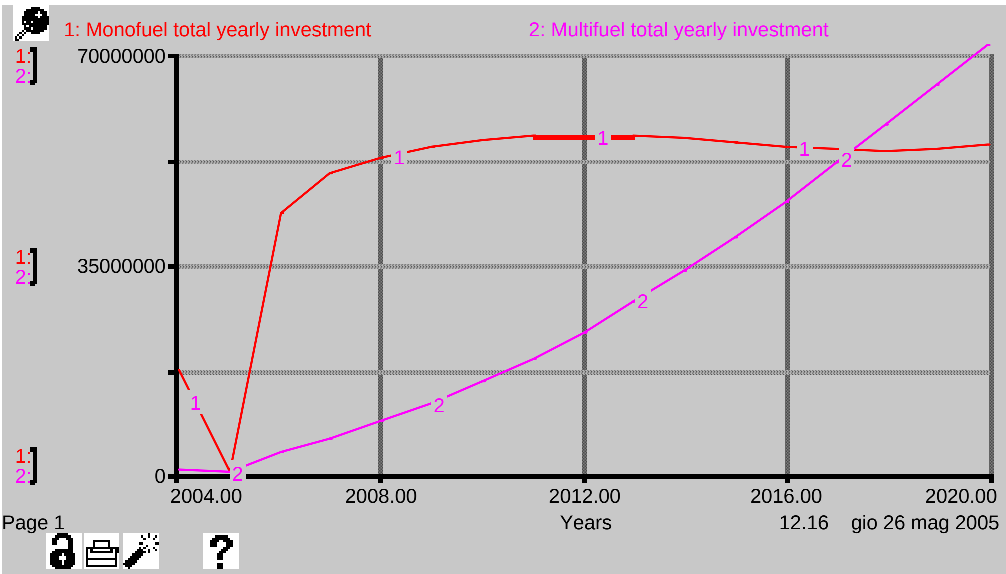


Graph no. (5): Numbers of mono-fuel and multi-fuel filling plants to build the following year.

The expanded network fosters, from 2006, the deployment of natural gas. The growing fleet lowers the ratio "cars per filling plant" generating an additional need for refueling facilities. Then, the reinforcing loop between natural gas-fueled car and natural gas filling stations is triggered.

Graph no (5) shows that mono-fuel plants keep the lead as number of stations to build only up to 2011. Then the competitiveness of multi-fuel prevails. After that mono-fuel plants stabilize slightly above 100 units per year level. At the same time multi-fuel plants contribute significantly to expand the network, passing from about 150 to 400 at end of period.

Investments follow the already described pattern for the first two years. Then, mono-fuel related investments skyrocket to 50-55 million Euros per year. They stay around this figure for all time span (see graph no. (6) below).



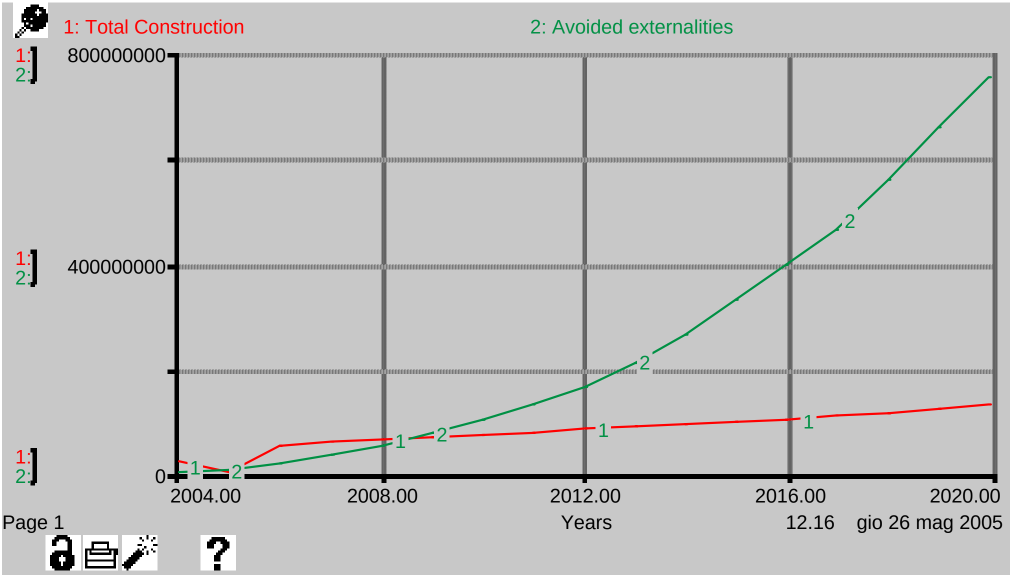
Graph no. (6): Investment requirements in nominal terms sorted plant type.

As regard multi-fuel plants, it goes from basically nothing to over 70 million Euros in 2020, the growth is constant and not far to be linear. It surpasses mono-fuel investments only in 2018 (58 million Euros *versus* 53 million Euros). This is the combination of two factors: the fast growing number of multi-fuel plants is offset by their cheapness, compared to building mono-fuel plants.

4.4 Externalities and Net Present Value (NPV) comparison

Externalities estimate should give an idea of what is the magnitude of monetary savings avoiding or restraining pollution. In this case I quantify the effect of avoiding gaseous pollution, global and local.

In the very first years, avoided externalities of the additional fleet are not able to balance the investments required to expand the infrastructure. But soon they gain foothold and from 2009 until 2020 they widen the gap, becoming even times bigger than the investments of those years (see graph no.(7) below). These are still nominal values that have to be discounted to be actually compared.



Graph no. (7): Total construction investments compared to avoided externalities.

Discounting the two streams at a rate of 5% the results are as follows in table no. (2):

NPV comparison		
Infrastructure investments	Externalities avoided	Gap
776.802.667 €	2.194.407.033 €	***1.417.604.367 €***

Table no. (2): Discounting refueling stations related investments and avoided externalities at 5% and comparing them.

Using Net Present Value technique, it becomes quite clear how much this last years gap can weigh. Indeed, even if they are far away in time, and therefore should count less in financial terms, avoided externalities are still more than twice as big as infrastructure.

Assuming different discount rates, tough, gives gaps that are sensitively different. For instance, discounting at 10% the gap halves it to about 700,000,000 Euros. 15% produces a even lower output: *circa* 380,000,000 Euros.

These results raise a couple of issues. The first one is that the model seems to give NPVs that can significantly change depending on the underlying discount rate. 380 million Euros is still a big figure, considering that we are coping with only 10% of the car fleet. Nevertheless, a

relatively small change in the discount rate provides savings estimate that are considerably different.
The second point is that discount rates are unlikely to rise as much as up to 15% in the years to come. Since 1999 Italy has been bound to the European Monetary Union that determines in perfect autonomy the monetary policy. The final aim of such a policy is to stabilize inflation and discount rates at low levels, so to foster stable economic growth. Therefore, it appears very unlikely that discount rates could rise, say, above 10%. This, too, has to be borne on mind when assessing the likelihood of 10% or 15% discount rates.

5. Conclusions

Although CH_4 has the highest hydrogen/carbon ratio of all hydrocarbons used in transport, it still has LCA CO_2 emissions that are not significantly lower than those of gasoline or diesel cars. It doubtless provide a positive contribution, but the effect on the overall fleet global emissions tends to be limited.
Conversely, natural gas has a competitive advantage over gasoline and diesel regarding some local pollutants. In particular, it is greener than gasoline with respect to CO, HC and O_3. In the case of natural gas fleet consisting of 10% of the total fleet by 2020, the reduction of the above mentioned pollutants is sound.
Different results derive, instead, from the cannibalization of diesel fueled cars. In this instance, the major contribution comes from limiting NO_X and soot emissions.
From a local point of view, it would be better to have a balanced mix of cars to cannibalize. This would lead to a more even reduction involving all local pollutants.
Concerning infrastructure, the take-off phase takes a couple of years. After this slow start, a booming request of new refueling plants occurs. While mono-fuel filling plants prevail at the beginning, multi-fuel dominate from 2011. Their competitiveness makes them the best option to increase the number of filling points without expanding the already oversized infrastructure.
On an overall level, infrastructure investments are bigger than avoided externalities in the first years. Then the growing natural gas-fuelled fleet generates its beneficial effects, contributing to boost the avoided externalities evaluation. When comparing the two discounted estimates, the pollution reduction weighs much more than infrastructure requirements.
Nonetheless, the results make clear how the model is sensitive to variations in the discount rate. Externalities always surpasses, in discounted terms, investments in infrastructure. What changes is the magnitude of their gap. For instance, in most of the simulations doubling the discount rate halves the gap. Whenever not only the sign but also the size of the gap mattered, this would be an issue to consider.
No matter this little uncertainty, the model gives a univocal answer: natural gas is a suitable answer in addressing some issues in the Transport industry. In particular, the biggest relief lies in air quality improvement. More efficient ways to curb global pollution, instead, have to be found through other solutions. The financially toughest phase would be at the beginning, when the infrastructure investments are bigger then avoided externalities. Here the Government should back this policy, knowing that the investments would be paid off in a few years.

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