POLITECNICO DI TORINO

Master of Science program in Energy and Nuclear Engineering

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Models and scenarios for energy planning - 02OKGND

TEMOA-ITALY Project Report

YUWEI SHI, s288123

QIFAN ZHU, s288338

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1. Introduction

The energy scenario for the EU is a complex and rapidly evolving landscape that encompasses a range of interconnected issues, including energy production, consumption, distribution, and policy. As the signing of The Paris Agreement to limiting global warming to well below 2 °C above pre-industrial levels, and pursuing efforts to limit the temperature increase to 1.5 °C, the EU has set an ambitious target of reducing its greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and achieving climate neutrality by 2050, which requires a significant and sufficient transformation of the EU's energy structure and system, including a rapid shift away from fossil fuels and towards renewable energy sources such as wind, solar, and hydropower, optimizing the network structure to reducing the losses and so on. As well as to implement strongly related energy policies and initiatives, including the Renewable Energy Directive, the Energy Efficiency Directive, etc.

Then, let's focus on Italy. Italy is a significant energy consumer and importer within the EU and has committed to reducing its greenhouse gas emissions and transitioning to a low-carbon economy. Italy is heavily dependent on imports of fossil fuels, particularly natural gas, and has relatively limited domestic energy resources. In 2019, fossil fuels accounted for over 80% of Italy's primary energy consumption, while renewable energy sources accounted for around 17%. However, in recent years, Italy has made significant progress in trying to increase the share of renewable energy in its energy mix. Furthermore, Italy has set a target of reaching 30% renewable energy in its final energy consumption by 2030 and has made significant investments in solar and wind power. Under the Paris Agreement and the EU effort-sharing legislation, Italy has committed to reducing its greenhouse gas emissions by 33% by 2030 compared to 2005 levels. In addition, a long-term goal of achieving climate neutrality by 2050 has been set as well.

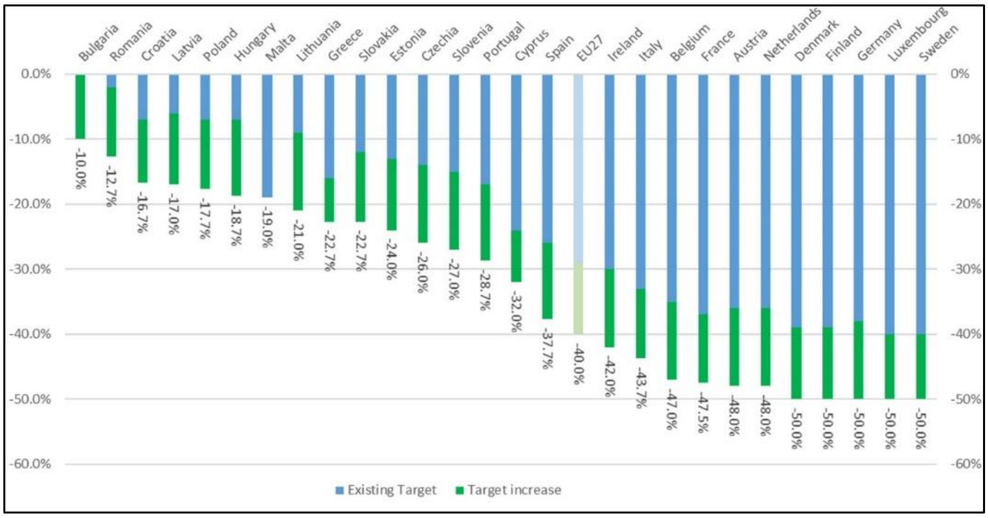

Figure 1.1 GHG reducing target for EU

To meet these targets, Italy has implemented a range of policies and initiatives aimed at promoting renewable energy sources, improving energy efficiency, and reducing greenhouse gas emissions. These include the National Energy and Climate Plan (NECP), which sets out Italy's energy and climate targets for 2030, and the National Recovery and Resilience Plan

(NRRP), which includes significant investments in renewable energy, energy efficiency, and sustainable mobility. In addition, Italy has implemented a range of measures to improve energy efficiency in buildings, promote electric vehicles, and support the deployment of renewable energy sources.

In this project, we would focus on one or more of the scenarios of IT, and do a simulation based on the TEMOA-Italy, which is an energy system optimization model (ESOM) to optimize the installation and utilization of energy technology capacity over a user-defined time horizon. It contains two sides: the supply side and the demand side, and the link connecting these two sides is called fuel technology. And the commodities are defined as different flows in and out of different 'technologies', including the demand flow, physical flow, and emission flow. On the demand side, there are four main sectors: industry, residential, commercial & agriculture, and transport.

All in all, in this project, our group is focusing on the transport sector, doing some simulation under the specific scenarios based on the TEMOA-Italy integrated some new 'technologies'.

2. Scenario definition

In this part, we are going to introduce and define some scenarios that would be applied in TEMOA-Italy. Briefly, there are two kinds of scenarios: Technology and Emission.

2.1 Technological Scenario

Introduce hydrogen-based technology to optimize the IT transport structure.

Improve the electrification level for the IT railway system.

Improve the hybrid powering technology to optimize the hybrid vehicles.

Currently, the EU and its member states have made a clear commitment to lead the way in environmental protection. But, at the same time, there is a need to ensure that European transport is safe and that its industry remains competitive on the global market.

With an increasing hydrogen penetration in the EU energy structure and the increasingly sophisticated technology of the fuel cell.

The hydrogen fuel cell (HFC) technology can be seen as one of the major zero-emission alternatives for powering transport. The HFC-based vehicles use a propulsion system like that of electric vehicles, where energy stored as hydrogen is converted to electricity by the fuel cell. In recent years, HFC transport solutions have been brought to the brink of commercialization. Many HFC-based buses and cars are in operation in the EU, and the hydrogen refueling infrastructure network is growing steadily as well. As of 2021, there are two hydrogen cars publicly available in select markets: the Toyota Mirai and the Hyundai Nexo.

Moreover, in the railway sector, hydrogen is a suitable environment-friendly energy carrier which shows the potentiality to replace diesel where electrification is not economically feasible. Some trials and pilot projects worldwide have successfully shown the adaptability of the HFC technology to the rail sector across various applications ranging from regional passenger trains to mining locomotives. For instance, there are already trains to operate in Germany, and the East Japan Railway Company has announced it will develop hydrogen fuel cell trains with expected delivery in 2024.

Figure 2.1 Alstom Coradia iLint – hydrogen fuel cell train in Germany

So, based on this situation we would like to set a scenario that introduces some HFC-based vehicles for Italy after 2020, applied in the model, to help to reduce the GHG emission of the transport sector.

When talking about the railway system, another aspect shouldn't be ignored is electrification. Electrification of railways refers to the process of powering trains with electricity rather than fossil fuels like coal or diesel. This is typically achieved by installing overhead wires, known as catenaries, or a third rail alongside the tracks. Generally, electric trains are more energy-efficient than diesel trains, which can help to reduce GHG emissions. They are also faster and quieter than diesel trains, which can improve the overall passenger experience.

Currently, the electrification railway system has been widely adopted by many countries around the world, including the United States, Europe, Japan, etc. And some countries even have already realized complete electrification, like Sweden and Switzerland. According to the data from the Swiss Federal Office of Transport, as of the end of 2020, 99.8% of the country's railway lines were electrified.

Now we talk about Italy, IT has a well-developed railway network that has been gradually electrified over the past century. As of 2021, the electrification level of Italy's rail system is approximately 72.2%, according to the data from Ferrovie dello Stato Italiane, while others still use diesel as a power source.

In recent years, IT has made great efforts to increase the electrification of its rail system as part of its broader goals to reduce GHG emissions and improve the sustainability of its transportation system. For example, in 2019, the Italian government announced plans to invest over €2 billion in railway electrification over the next five years.

So, in this situation, we are willing to add 'Improve the electrification level for IT railway system' as a part of our technological scenario.

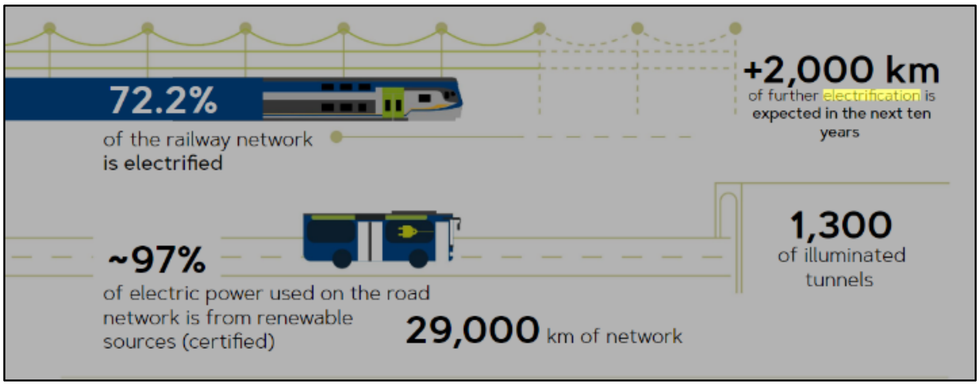

Figure 2.2 Electrification level of IT railway system from Ferrovie dello Stato Italiane

Regarding the last part of our technological scenario, in recent years, plug-in hybrid vehicles have become increasingly popular in the EU, as they offer the advantages of both electric and ICE vehicles, including reduced emissions and improved fuel economy. According to the European Alternative Fuels Observatory, there were over 1.5 million PHEVs on the road in the EU by the end of 2020. Considering the gradually increasing market, we can assume that there would be some technological improvements in the performance of PHEVs and reduce the emission furtherly, like battery technology improvement, advancements in electric motor technology, or advances in hybrid powertrain technology that help improve the hybridization ratio of PHEVs.

2.2 Emission Scenario

Italy, like many other countries, faces challenges in reducing its transport emissions. According to data from the UNFCCC, in 2016, the transport sector was responsible for 23.9% of Italy's total GHG emissions, which is the largest source of GHG emissions in IT. In contrast to the industry and public electricity and heating sectors, transport emissions are still just above 1990 levels.

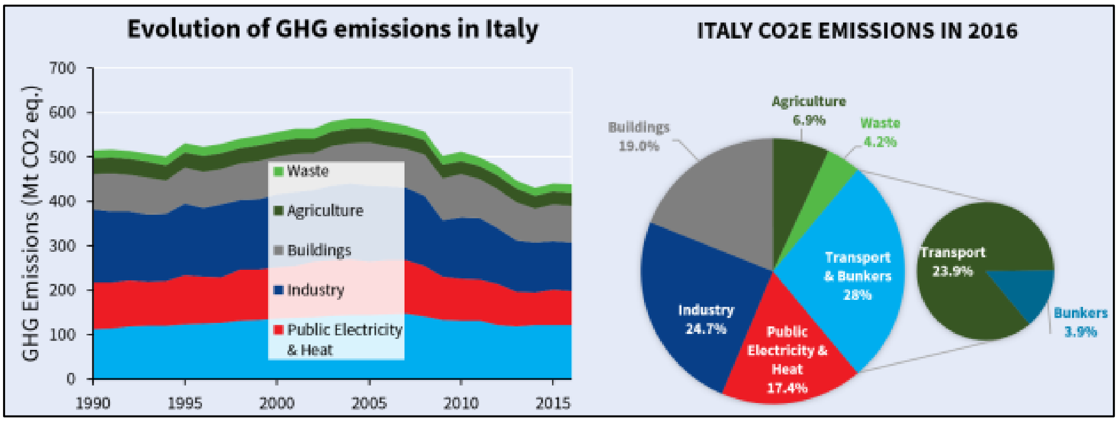

Figure 2.3 Evolution and 2016 share of Italian CO2e emissions

In the context of needing to be decarbonized by the mid-century under the Paris Agreement and a goal to reduce the GHG emission by 33% by 2030 compared to 2005 levels, which Italy has declared already, <u>we set this emission scenario. But considering some constraints from the cost, technology, and exceptional circumstances, we put in some elasticity that to decrease by 25% in 2030 and reach the final 33% reduction goal in 2040 at least</u>.

Finally, the objective of this scenario is to show how Italy can decrease its transport emissions by transferring its transport structure. In particular, the scenario focuses on reductions in road transport and railway transport emissions and enforces an available emissions reduction target in 2040 compared to 2005 (33% reduction).

3. Description of the Reference Energy System

3.1 RES & New Technology

In this project, the reference energy system (RES) is based on TEMOA-Italy, as said before, it is a bottom-up technology-rich model with the capability to model a complex RES including the techno-economic description of the technologies, the drivers for the demand projection, and so on.

It is composed of four demand-side sectors (buildings, transport, commercial & agricultural, and industry) and two supply-side sectors (upstream and the power sector). While the demand-side sectors consume energy to satisfy final energy service demands, the supply-side sectors produce the energy commodities consumed by the demand-side. The link between the two sides is defined as fuel technology.

Regarding our topic, it is only focused on the transport sector on the demand side.

For the original model (database) without any modification, in the transport sector, we can notice that it is a model framework to forecast or generate a trend of transportation structure in a long-time horizon from 2006 (base year) to 2050 with a driver of wide demands from POP, GDP and so on. One of the most important is that the demand has an elasticity related to the region, period, and driver, which means that by changing one of these three elements, the specific demand can be modified, which may provide an opportunity to link with some economic models. Another important thing is the technology, in this system, a lot of things can be defined as 'technology', take the example of the transport section and its upstream, the vehicle that consumes energy or fuel could be seen as a technology, the plant that producing energy or fuel could also be seen as technology, even with the link between two sides should be seen as a 'fuel technology'. The advantage of this technology logy is that it could make the database optimize easily but not simplify, with some constraints like Max/Min capacity, efficiency, lifetime, and so on. The last but not least, the database also consists of some economic elements including the cost investment, fixed cost, variable cost, and related factors, with which we could do an economic analysis to evaluate the technologies or technology groups.

Overall, depending on the database elements and the scenarios described before. We would like to add the hydrogen fuel cell technology as the new fuel technology integrated to the database named 'TRA_FT_FC_N', and related transport technologies should be inserted as well, as follow:

1. hydrogen fuel cell-based car: 'TRA_ROA_CAR_FC_N'

2. hydrogen fuel cell-based bus: 'TRA_ROA_BUS_FC_N'

3. hydrogen fuel cell-based passenger train: 'TRA_RAIL_PAS_FC_N'

```sql
INSERT INTO "technologies" VALUES ('TRA_ROA_BUS_FC_N','p','TRA','Buses - Fuel Cell - New',''); -- self_insert
INSERT INTO "technologies" VALUES ('TRA_ROA_CAR_DST_N','p','TRA','Cars - Diesel - New','');
INSERT INTO "technologies" VALUES ('TRA_ROA_CAR_ELC_N','p','TRA','Cars - Full-electric - New','');
INSERT INTO "technologies" VALUES ('TRA_ROA_CAR_GSL_N','p','TRA','Cars - Gasoline - New','');
INSERT INTO "technologies" VALUES ('TRA_ROA_CAR_HYBG_N','p','TRA','Cars - Gasoline hybrid - New','');
INSERT INTO "technologies" VALUES ('TRA_ROA_CAR_LPG_N','p','TRA','Cars - LPG - New','');
INSERT INTO "technologies" VALUES ('TRA_ROA_CAR_NGA_N','p','TRA','Cars - Natural gas - New','');
INSERT INTO "technologies" VALUES ('TRA_ROA_CAR_PIHYB_N','p','TRA','Cars - Plug-in hybrid - New','');
INSERT INTO "technologies" VALUES ('TRA_ROA_CAR_FC_N','p','TRA','Cars - Fuel Cell - New',''); -- self_insert
INSERT INTO "technologies" VALUES ('TRA_ROA_HTR_DST_N','p','TRA','Heavy trucks - Diesel - New','');
```

Figure 3.1 The Code of new technology example.

3.2 Techno-Economic Characterization and Modification

The techno-economic characterization of added technology is as bellow:

Table 3.1 Some techno-economic characterization of new technology

	Fuel technology	Transport technology		
Name	TRA_FT_FC_N	TRA_ROA_CAR_FC_N	TRA_POA_BUS_FC_N	TRA_RAIL_PAS_FC_N
Efficiency	1 PJ/PJ @2020	0.7 Bvkm/PJ @2020[1] 0.91 Bvkm/PJ @2050	0.1 Bvkm/PJ @2020[1] 0.12 Bvkm/PJ @2050	1.0 PJ/PJ @2020 1.2 PJ/PJ @2050
Min/Max capacity installation	0.32*45 PJ [3] 0.32*63 PJ [3] @2020	/	/	/
Min/Max activity	/	/	/	/
Lifetime	20	12 [2]	12[2]	/
Fixed and variable O&M	1.0 @2020	66.7 M€/Bvkm @2020	66.7 M€/Bvkm @2020	/
Investment cost	50 @2020	2636 M€/Bvkm @2020 [2]	3515 M€/Bvkm @2020 [2]	/

The value highlighted in yellow is an assumption value.

[1] Lerede, D., Bustreo, C., Gracceva, F., Lechón, Y., & Savoldi, L. (2020). Analysis of the Effects of Electrification of the Road Transport Sector on the Possible Penetration of Nuclear Fusion in the Long-Term European Energy Mix. Energies, 13(14), 3634.
[2] Lerede, D. (2019). Effect of Electrification of the transport sector for the EUROfusion TIMES Model [Tesi di Laurea Magistrale]. Politecnico di Torino.
[3] European Commission, Directorate-General for Energy, Vautrin, A., Bossmann, T., Beaussant, O. (2021). METIS study on costs and benefits of a pan-European hydrogen infrastructure: in assistance to the impact assessment for designing a regulatory framework for hydrogen: METIS 3, Study S3, Publications Office.

We collect the data on the efficiency of hydrogen fuel cell-based cars and buses from the source [1] and assume that the efficiency would be growing at 130% and 120% for cars and buses separately.

Regarding the investment cost in source [2], we transfer the value from M$/Bvkm into M€ /Bvkm. And depending on the figure of ‘Selected Investment cost trends for Cars’ [2], we made an assumption to get the investment cost in 2050 for both cars and buses.

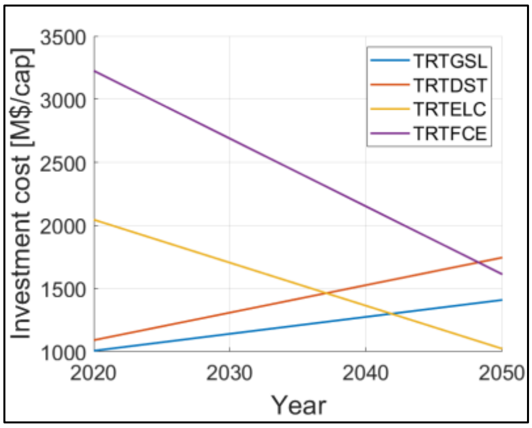

Figure 3.2 Investment cost trend for 'TRA_ROA_CAR_FC_N' [2]

And for the source [3], we could get the data about hydrogen trend under the simulation authored by the EU commission and after transferring the value in TWh into PJ multiplied by 32% (a factor representing a transportation sector's percentage in total energy consumption in IT), we get the maximum capacity value and minimum capacity value in 2020 that are needed to set the constraints for hydrogen fuel cell fuel technology.

Regarding the factor (32%), according to data from the International Energy Agency (IEA), in 2019, the transportation sector accounted for approximately 32% of Italy's total final energy consumption. This includes energy used in all modes of transportation, including road, rail, air, and water transport.

In detail, we set the hydrogen demand data as the source of maximum capacity, and the hydrogen production value as the source of minimum capacity. Then a rough assumption to get the assumed value is 2050, which represents the production growth and demand growth along the timeline and as the constraint to make sure that the generated value would not be unrealistic.

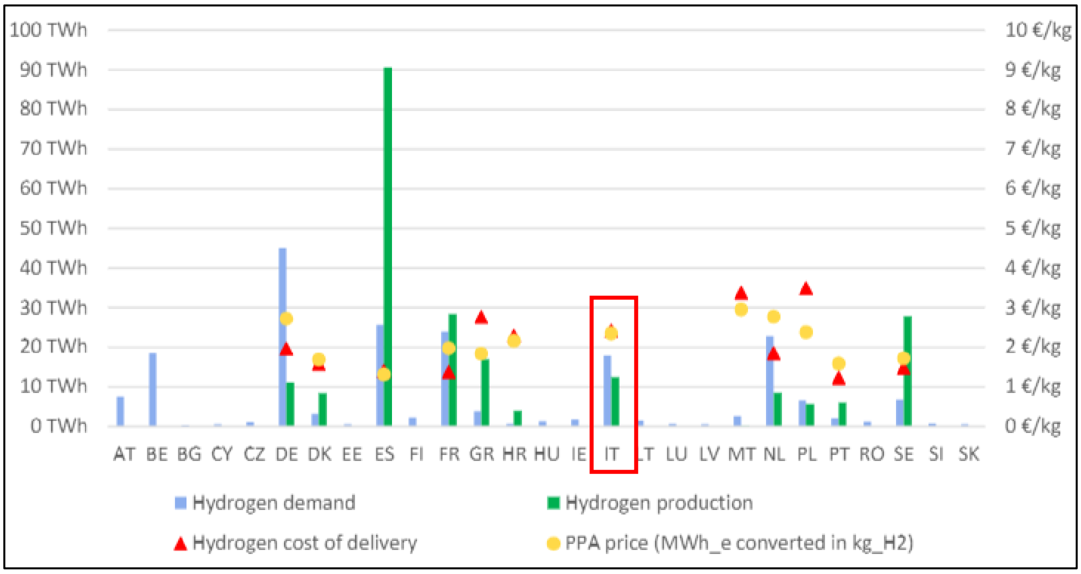

Figure 3.3 Hydrogen trend assumption for EU [3]

Finally, with these techno-economic characteristics of new technologies, depending on the scenarios defined in the last section, we could make some modifications to the database.

1. Modify the 'TechInputSplit' to increase the electrification level of Passenger trains and realize the complete passenger railway electrification.

```sql
INSERT INTO "TechInputSplit" VALUES ('IT',2007,'TRA_DST','TRA_RAIL_PAS_E',0.23,'');
INSERT INTO "TechInputSplit" VALUES ('IT',2007,'TRA_ELC','TRA_RAIL_PAS_E',0.77,'');
INSERT INTO "TechInputSplit" VALUES ('IT',2010,'TRA_DST','TRA_RAIL_PAS_E',0.15,'');
INSERT INTO "TechInputSplit" VALUES ('IT',2010,'TRA_ELC','TRA_RAIL_PAS_E',0.85,'');
INSERT INTO "TechInputSplit" VALUES ('IT',2020,'TRA_DST','TRA_RAIL_PAS_E',0.07,''); -- SELF_INSERT FOR SCEN
INSERT INTO "TechInputSplit" VALUES ('IT',2020,'TRA_ELC','TRA_RAIL_PAS_E',0.93,''); -- SELF_INSERT FOR SCEN
INSERT INTO "TechInputSplit" VALUES ('IT',2030,'TRA_DST','TRA_RAIL_PAS_E',0.00,''); -- SELF_INSERT FOR SCEN
INSERT INTO "TechInputSplit" VALUES ('IT',2030,'TRA_ELC','TRA_RAIL_PAS_E',1.00,''); -- SELF_INSERT FOR SCEN
```

Figure 3.4 Code for passenger railway electrification

As Figure 3.4 shows, we increase the percentage of electricity gradually from 0.85 (original value) to 0.93 and finally reach 1.00 as the complete electrification. Regarding the railway for the Freight train, considering the possible high investment cost, we would not change that value now.

2. The second one is to modify the commodities that flow into the Plug-in hybrid vehicle. As shown below, we assume that the Plug-in-Hybrid technology would be improved in the period to 2030, so that the usage of electricity and diesel (hybridization ratio) roughly equals 50:50 for cars, while the ratio would be a little low for light commercial vehicles at 0.48:0.52.

```sql
INSERT INTO "TechInputSplit" VALUES ('IT',2016,'TRA_GSL','TRA_ROA_CAR_PIHYB_N',0.55,'');
INSERT INTO "TechInputSplit" VALUES ('IT',2016,'TRA_ELC','TRA_ROA_CAR_PIHYB_N',0.45,'');
INSERT INTO "TechInputSplit" VALUES ('IT',2030,'TRA_GSL','TRA_ROA_CAR_PIHYB_N',0.50,''); -- SELF_INSERT FOR SCEN
INSERT INTO "TechInputSplit" VALUES ('IT',2030,'TRA_ELC','TRA_ROA_CAR_PIHYB_N',0.50,''); -- SELF_INSERT FOR SCEN
INSERT INTO "TechInputSplit" VALUES ('IT',2020,'TRA_DST','TRA_ROA_LCV_PIHYB_N',0.55,'');
INSERT INTO "TechInputSplit" VALUES ('IT',2020,'TRA_ELC','TRA_ROA_LCV_PIHYB_N',0.45, '');
INSERT INTO "TechInputSplit" VALUES ('IT',2030,'TRA_DST','TRA_ROA_LCV_PIHYB_N',0.52,''); -- SELF_INSERT FOR SCEN
INSERT INTO "TechInputSplit" VALUES ('IT',2030,'TRA_ELC','TRA_ROA_LCV_PIHYB_N',0.48,''); -- SELF_INSERT FOR SCEN
```

Figure 3.5 Code for hybridization ratio in PIHYB vehicles

3. Then we are going to insert some emission limits to support our scenario. Because it is not easy nor not necessary to control the GHG emissions for each specific flow, we just simply set a limit on each GHG of the total transport sector in each scenario applied year. And the model would automatically solve and generate a transport activity structure that can satisfy our emission goals.

```sql
INSERT INTO "EmissionLimit" VALUES ('IT',2025,'TRA_CH4',5473,'Kt',''); -- SELF_INSERT --SCEN-12%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2025,'TRA_CO2',126606,'Kt',''); -- SELF_INSERT --SCEN-12%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2025,'TRA_N2O',7961,'Kt',''); -- SELF_INSERT --SCEN-12%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2030,'TRA_CH4',4666,'Kt',''); -- SELF_INSERT --SCEN-25%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2030,'TRA_CO2',108005,'Kt',''); -- SELF_INSERT --SCEN-25%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2030,'TRA_N2O',6784,'Kt',''); -- SELF_INSERT --SCEN-25%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2040,'TRA_CH4',4179,'Kt',''); -- SELF_INSERT --SCEN-33%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2040,'TRA_CO2',96265,'Kt',''); -- SELF_INSERT --SCEN-33%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2040,'TRA_N2O',6060,'Kt',''); -- SELF_INSERT --SCEN-33%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2050,'TRA_CH4',3809,'Kt',''); -- SELF_INSERT --SCEN-40%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2050,'TRA_CO2',84805,'Kt',''); -- SELF_INSERT --SCEN-40%GWP
INSERT INTO "EmissionLimit" VALUES ('IT',2050,'TRA_N2O',5426,'Kt',''); -- SELF_INSERT --SCEN-40%GWP
```

Figure 3.6 Code for Emission limit

Regarding the value we input into the model, it is based on the emission results that were generated in the RES condition integrated with our new technologies in 2007. As said in the scenario definition, we will set a goal that the emission reduction should be reaching at least 33% in 2040.

Table 3.2 Emissions goals for the transport sector in the model

Year	Template year:2007	2025	2030	2040	2050
%	100%	88%	75%	67%	60%
CO_2-eq (kt)	3041036	2652351	2260527	2019404	1808421

These are the emission goals, we defined, to reach a 33% reduction in 2040, and finally, decrease by 40% in 2050. The template year is 2007.

Regarding the specific value above, we design a methodology based on GWP to define them:

At first, the real physical amount of all GHG (CO2, CH4, N2O) in the model should be converted to a CO2 equivalent value based on their specific GWP.

Then the sum can be calculated, and according to the emission goal, the target sum value of each scenario applied year can be calculated.

Thirdly, according to the data generated in the RES condition, the percentage of emission (in CO_2-eq) for each gas (CO2, CH4, N2O) in each year can be determined.

Fourthly, the emission limit (in CO_2-eq) of each gas (CO2, CH4, N2O) can be calculated by allocating the total target (sum) value (calculated in the second step), based on their percentage (calculated in the third step).

Finally, the emission limit (in CO_2-eq) of each gas (CO2, CH4, N2O) should be converted back to the real physical amount. And this is the value we put into the model.

4. The last one is about the 'CommodityEmissionFactor' for new technology, but considering the hydrogen fuel cell is a relatively clean energy technology, this value can be seen as '0'.

4. Result analysis

In this part, we are going to analyze the results generated under our scenarios and the base scenario (RES). All the data will be presented in figures to clearly show the changes in emissions and transport structure as a result of the scenarios applied.

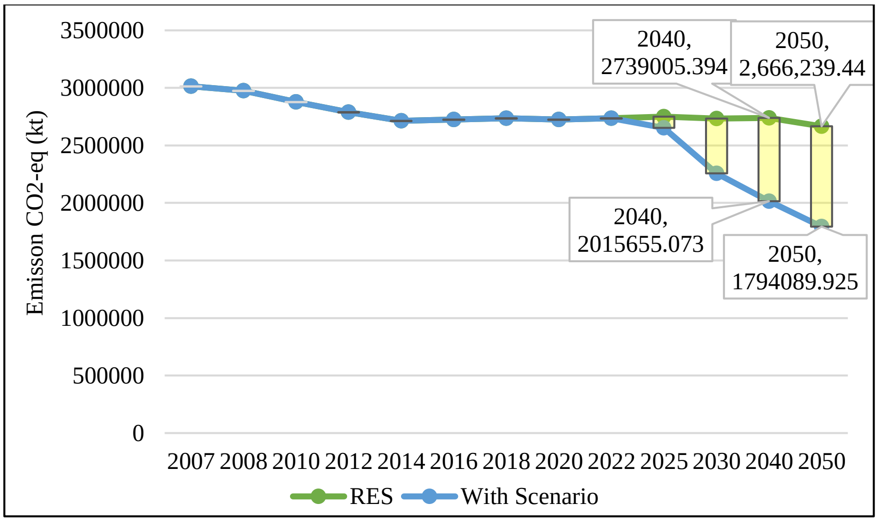

Figure 4.1 GHG Emission trend of RSE and with scenarios

From figure 4.1, we can see that the total emissions in the transport sector have been reduced because of the technological scenarios and emission scenarios. In 2040, the emission value decreased from 2,739,005 (RES) to 2,015,655 (with scenario), with a 26.4% reduction. And compared to the emission in 2007 (3,014,036), the reduction is about 33.2%. Regarding the emission in 2050, it has a further reduction to 40.5% compared with the value in 2007.

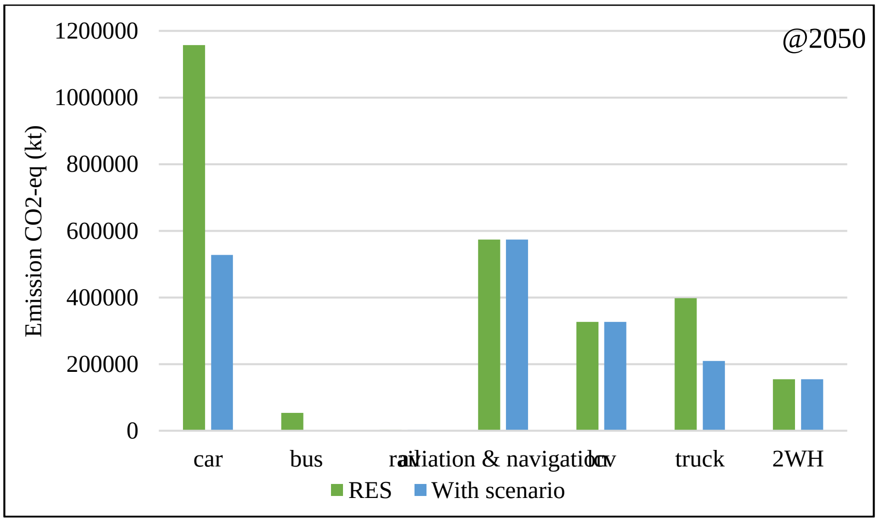

Figure 4.2 GHG Emission in different transport technologies @ 2050

From the last figure, it can be noticed that for the total GHG emission reduction, the car part provides the greatest contribution: the emissions have been reduced by more than 50%. And under the scenarios, the buses would realize ‘0’ GHG emissions in 2050. It is because all the buses are electric at that time or maybe combined with some use of Hydrogen Fuel cell technology that we introduced.

Regarding the truck part that includes heavy trucks and medium trucks, the emissions were reduced by about 45%, which is the complete effort of vehicle electrification replacing those using traditional fossil fuel as a power source.

For the other parts of the transport sector, there are not any large changes between RES and the situation with scenarios, this may be because our new technology has not been introduced to these parts, and carrier electrification has not been widely used in these fields.

But we can imagine that if carrier electrification can be applied to these fields, we would get a more significant reduction in GHG emissions.

Then based on the demand across every selected year, we can generate a figure regarding the GHG emission per Bvkm, it is a ratio that can represent the advancement of vehicles' energy performance.

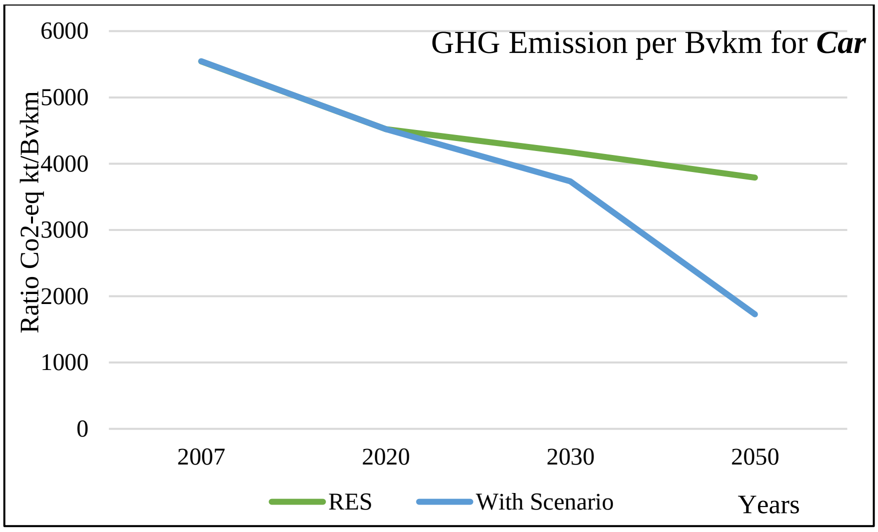

Figure 4.3 GHG Emissions per Bvkm for Car

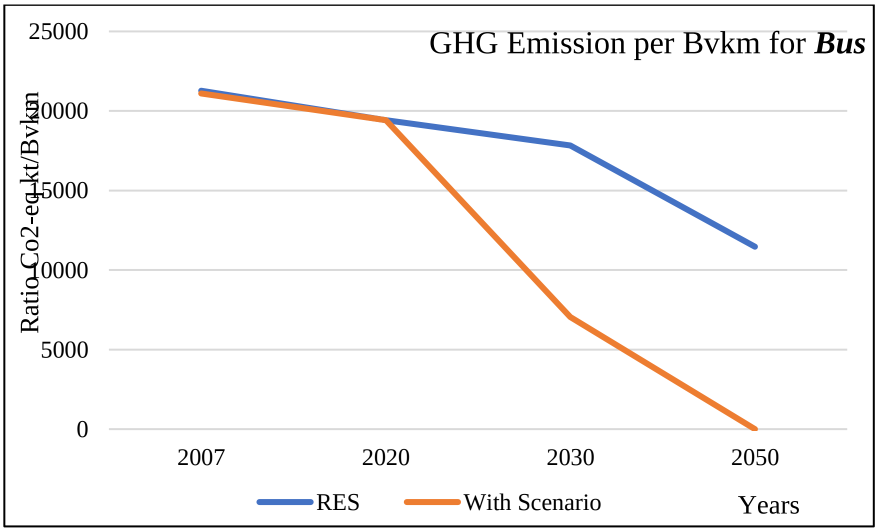

Figure 4.3 GHG Emissions per Bvkm for Bus

As we expected, this ratio is decreasing along the timeline because of the scenarios we set. This means for the same length of driving demand, less and less GHG emission would be produced in the process.

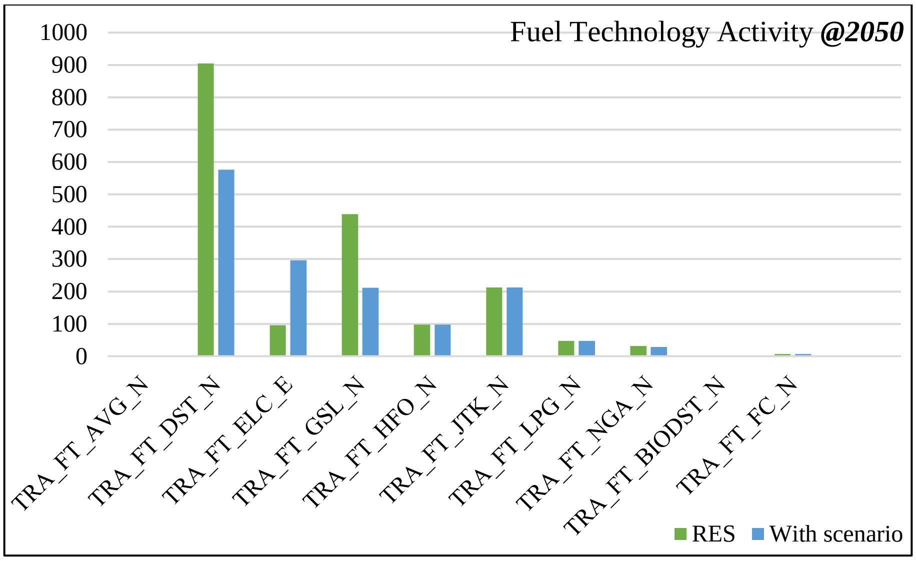

Figure 4.4 Activity of Fuel technology @ 2050

As we analyzed before, the reason why the emission reduction at the same driving demand is the transformation of the fuel technology activity structure and transport technology activity structure. From the figure above, we can see that, in 2050, the diesel and gasoline fuel technology activity unit amount under the scenarios reduce heavily compared with that in RES, while the electricity fuel technology activity increases sharply at 3 times because of the emission limit, which means that the amount of diesel and gasoline commodities that could flow into the transport technology would be decreased as a result, while the electricity commodity would increase. And more and more electricity commodities and electric vehicles would be selected to be used by the model in solving process.

Regarding figure 4.5 below, demonstrates that for the reason of scenario along the timeline from 2022 (no scenario applied) to 2025 (the first year for scenario applied), then to 2050 (the final year in the model), the unit amount of different fuel technologies' activities would change step by step to automatically modify the physical commodities, to satisfy with the emission limit at the output.

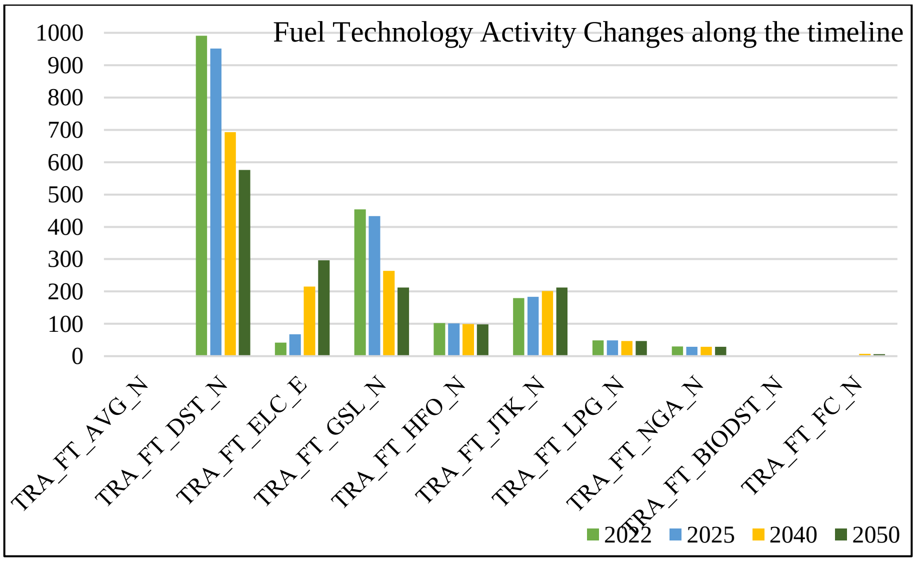

Figure 4.4 Fuel Technology Activity Changes along the timeline

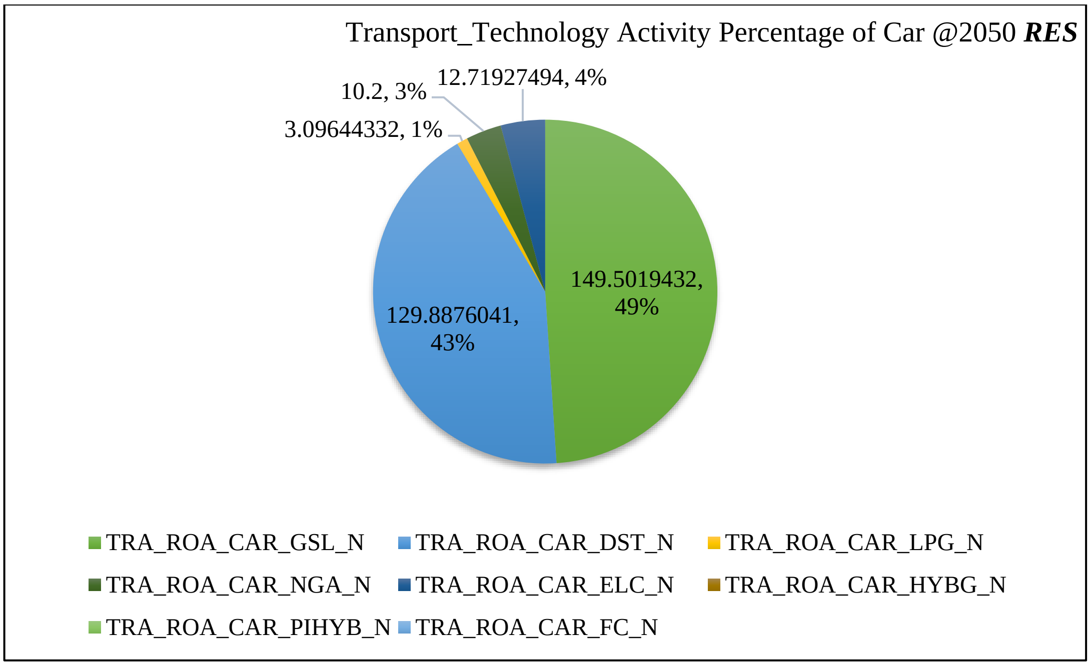

Figure 4.5 Transport Technology Activity Percentage of the car @ 2050 RES

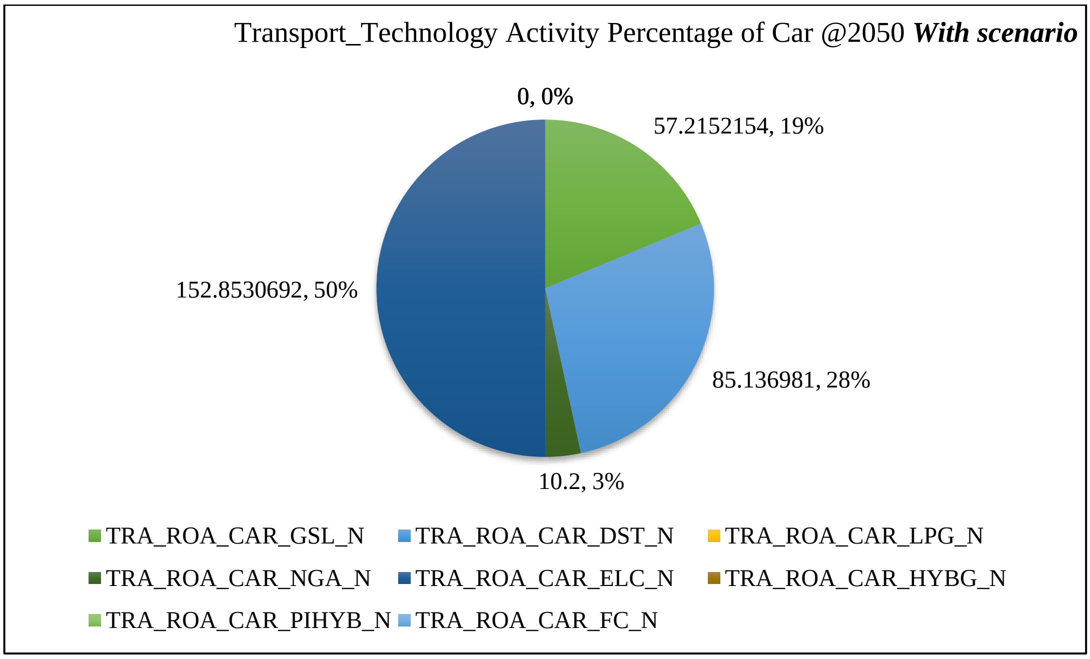

Figure 4.6 Transport Technology Activity Percentage of the car @ 2050 with scenarios

These two figures show the changes in car activities used to satisfied with the demand, in 2050, in the RES condition diesel car still capture a very large part of total car activities at 43%, while it reduced to one-quarter of the total activities in the condition of scenarios because the diesel fuel still causes GHG emissions even if they use the new diesel technology. For the Plug-in hybrid car, it occupies almost half of the total car activities in RES, while the percentage reduces to only 19% for scenarios. This kind of car combined the technology of both electric vehicles and fossil fuel vehicles, so it provides an ability to reduce the emission in the driving process than completely fossil fuel vehicles. But under a stricter emission limit environment, the model (car activity) prefers to directly use completely electric vehicles rather than PIHYB vehicles. So, we can see a significant increase in electric vehicle percentage in the total car technology activities, from 4% in RES to 50% in a situation with the scenario. In other words, the model selected an electric vehicle to respond to a stricter emission limit requirement with the same driving demand.

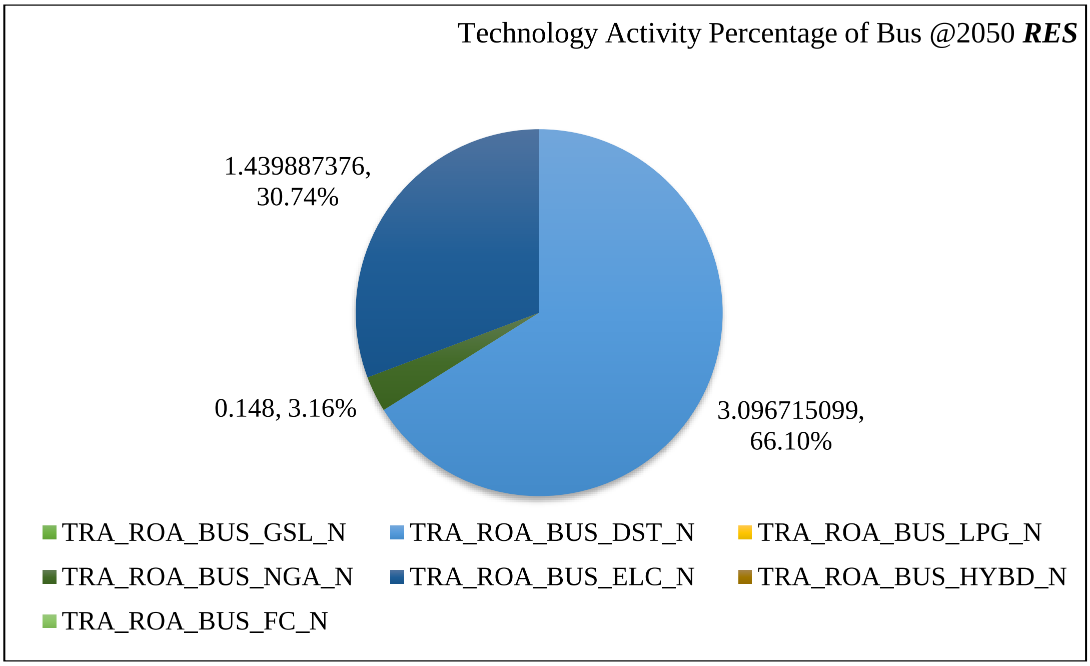

Figure 4.7 Transport Technology Activity Percentage of bus @ 2050 RES

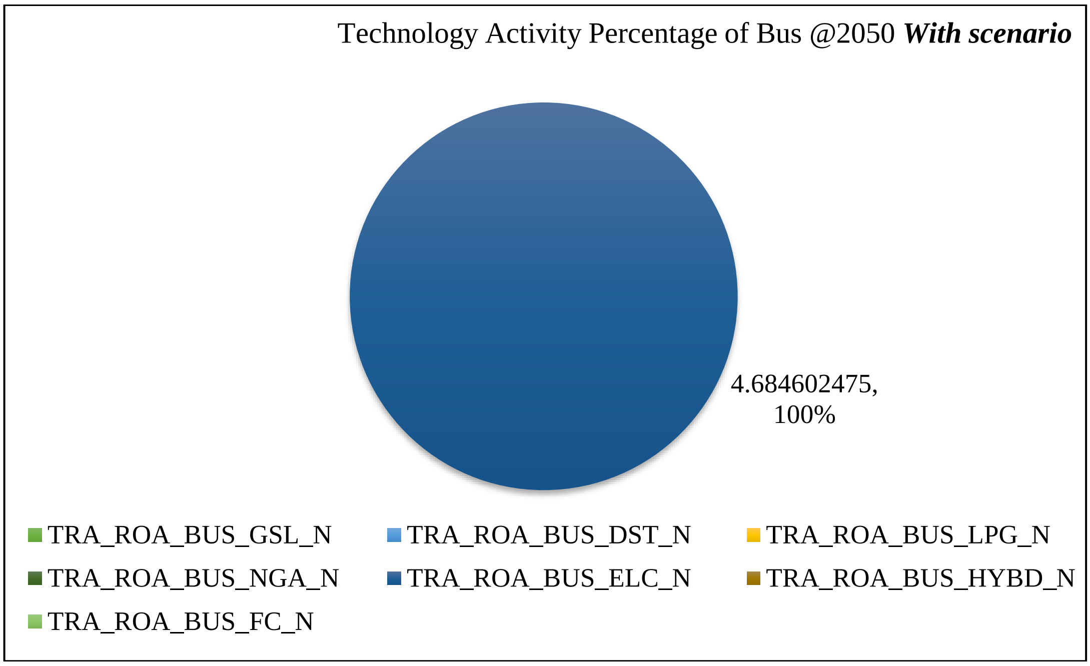

Figure 4.8 Transport Technology Activity Percentage of bus @ 2050 with scenario

Figure 4.7 and 4.8 is about the bus technology activities in 2050, the former one representing RES shows that about 66% of the total bus activities is using diesel as a power source. The diesel-driving bus is still a key element in that condition, which is similar to that in the car activity structure. On the other hand, approximately 30% of the bus activities are from the electric bus in RES condition, while this value increases to a surprising 100% in the condition with scenarios shown in figure 4.8. It means that the system satisfied all driving demands by just using electric buses. So, in this case, no GHG emissions would be produced.

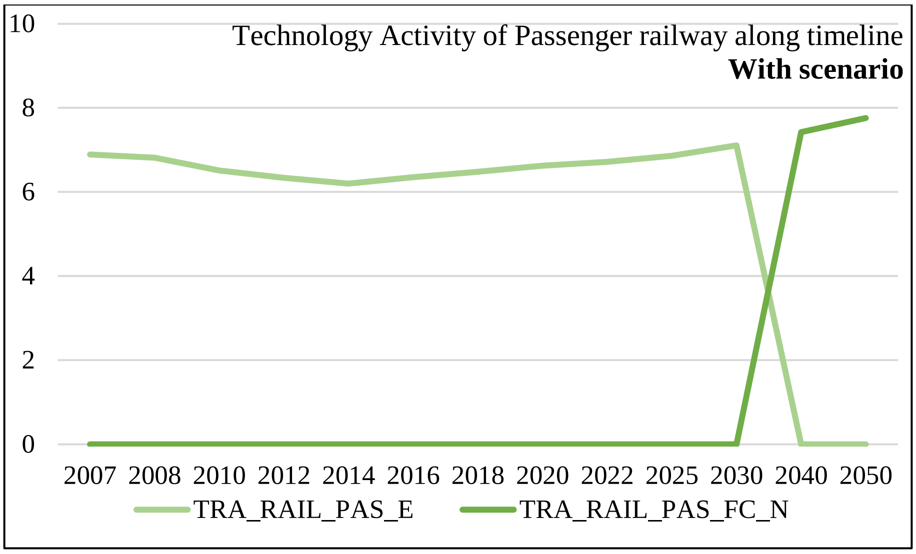

Figure 4.9 Transport Technology Activity of Passenger railway along the timeline with scenario

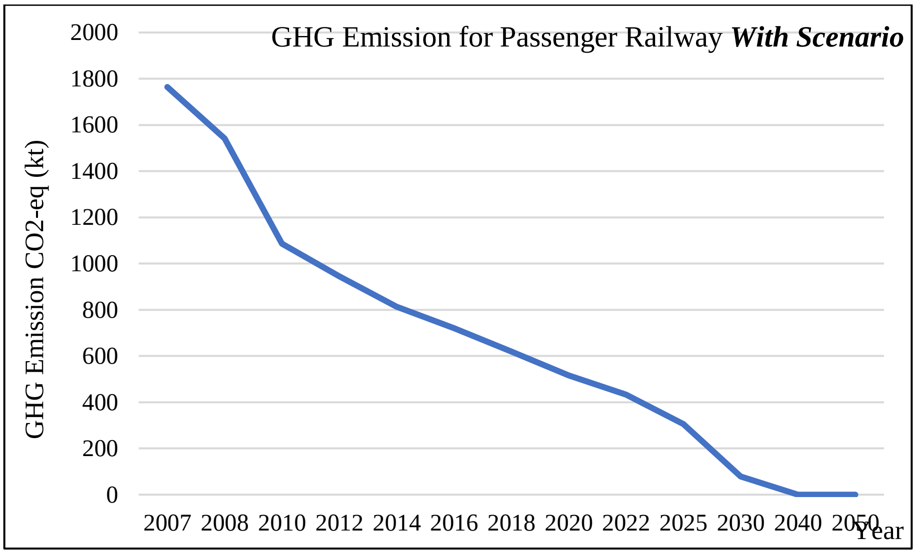

Figure 4.10 GHG Emission for Passenger Railway with Scenario

Figure 4.9 and 4.10 represents the situation of Passenger railway activity. From figure 4.9, we can see that all the passenger railway activities are driven by hydrogen fuel cell trains rather than the original passenger railway from 2040.

Figure 4.10 gives information regarding the GHG emission from passenger railway activity. And there are two significant decreasing along the timeline: the period from 2008 to 2010 and the period from 2025 to 2030 can be noticed, it is because we set a scenario regarding electrification. This scenario provides the ability to increase electricity usage and decrease diesel usage for passenger railway technology ‘TRA_RAIL_PAS_E’ activity.

For the emission from 2040, the value is ‘0’, it is because of the realization of complete railway electrification and the usage of HFC technology. Both elements would not cause nominal GHG emissions generally.

5. Improvement

After the analysis, we noticed that some inadequacies need to be improved and revised for our database. So, a little coding for changing is going to proceed.

1. The first change is about the electrification level for freight railways. In the last scenario, considering the relationship between cost and profit & PBT, we just change the electrification level for the passenger railway. But at this time, we assume that the complete electrification process of the passenger railway in 2030 promotes a more mature technology that costs less, and most of the railway network in Italy is already equipped with electrification devices. So that the total cost for freight railway electrification could be affordable.

2. The second change is that we set a new more ambitious scenario on emission limit to keeping the same pace as Italy's emission target: GHG emissions are reduced by 33% by 2030. Moreover, we are also going to try to realize the nearly '0' emissions produced by the transport sector excluding aviation and navigation.

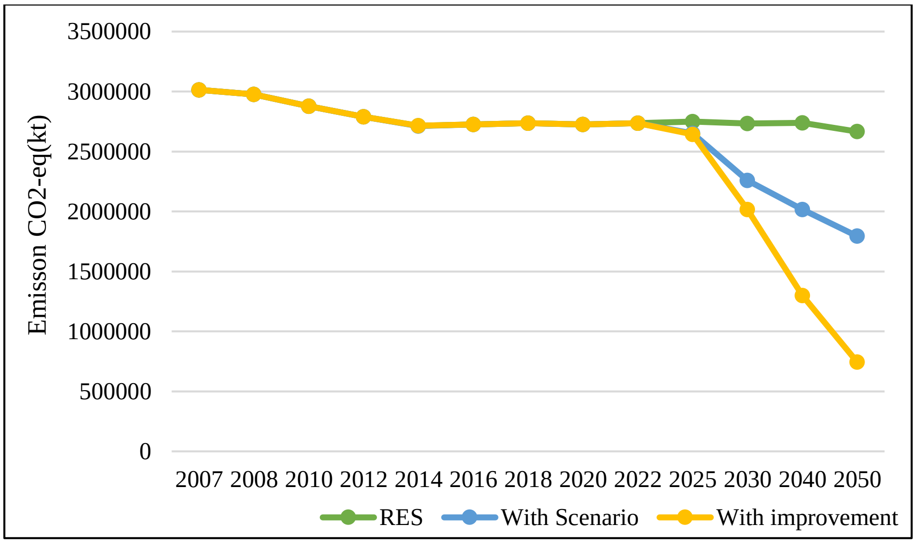

Figure 5.1 GHG Emission trend of RSE and with scenarios and with improvement

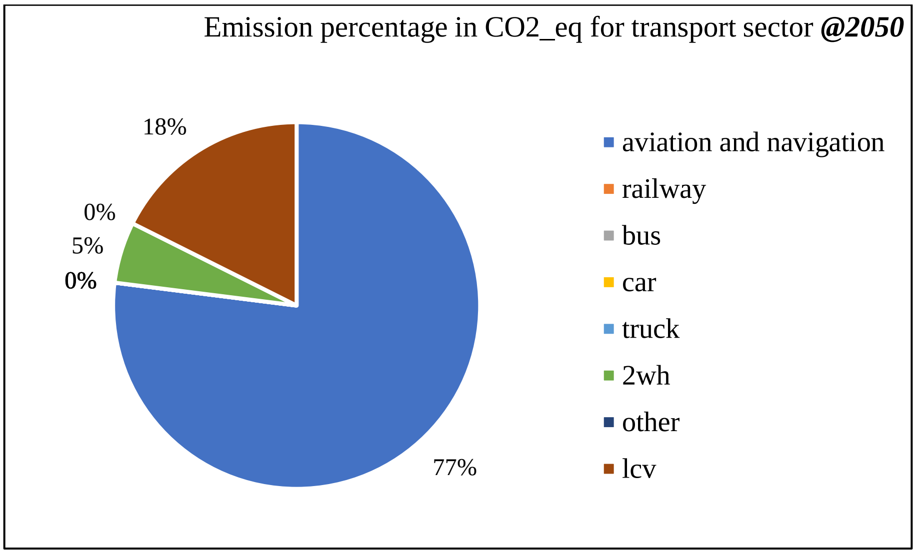

Figure 5.2 Emission percentage in CO2_eq for the transport sector in 2050

Figure 5.1 shows the emission trend after the modification in the database, the total emission in 2050 reaches one-third of that in RES. And to reach this situation, vehicles should be highly electrification or use hydrogen fuel cell technology which would not cause much GHG emission in the driving process generally.

From figure 5.2, we can see that under the environment with a more ambitious emission target, the most GHG emission (77%) comes from aviation and navigation because they only use fossil fuels like aviation gasoline and heavy fuel oil in our database. Another 23% is composed of emissions from two-wheeler and light commercial vehicles because we haven't set any constraints on both.

3. Considering a strongly dependent on electric vehicles to reduce GHG emissions to reach the green target, which has been shown by our data and results. We have to mention a new technology on electric vehicles called V2G that is a technology enables electric vehicles to interact with the power grid by allowing them to charge and discharge electricity, which means it allows electric vehicles to not only consume electricity from the grid to charge their batteries but also to send electricity back to the grid when they are not in use or when the grid requires additional power.

Moreover, it allows electric vehicles to act as mobile batteries, providing a source of backup power to the grid during periods of high demand or power outages. It can also help to balance the load on the grid by allowing electric vehicles to charge during off-peak hours when demand is low and then discharge during peak hours when demand is high.

Introducing this technology into the database may be concerning not only the transport sector but also the power sector in the supply side and related paraments including storage, daytime, efficiency, and so on.

6. Conclusion

Currently, the energy system models have become more and more crucial to assess the effectiveness of possible energy policies in pursuing the declared environmental objectives. TEMOA-Italy, as a bottom-up technology-rich model, can provide a relatively effective and accurate result for different sectors of the Italian energy system under different scenarios.

In this project, we have modified the database by setting two kinds of scenarios separately on technology and emission limit, based on the Italy target for GHG emission reduction, and introducing a new technology 'hydrogen fuel cell'. After the database construction and solving, we successfully got the simulated results from TEMOA-Italy.

According to the result, to realize the emission target in 2030, and carbon neutrality in 2050, the transport structure should be optimized positively, and fully electric carriers should be widely promoted ranging from two-wheelers, cars, and buses to railways. But considering the possibility of high costs including investment and O&M, the technologies should be improved to increase efficiency and lifetime. Meanwhile, the governments can provide financial incentives such as tax credits, and rebates to encourage consumers to purchase electric carriers.

Furthermore, from the result in the last part that tries to achieve nearly '0' emission, it should be pointed out that emissions from aviation and navigation would occupy an unignored amount of transport emission. In order to reach a stricter green target, something should be developed to solve this problem in the future.

7. Reference

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Individual Workload - Instruction

The following table should be filled providing the individual contribution (from 0 % to 100 %, the sum of the two contributions to each phase must be 100%) to the different project parts and during the different project phases. Then, the table must be included in your report (in the last page).

N.B.: The individual workload will be considered during the evaluation of the project.

Project phases	Project parts	Shi Yuwei S288123	Zhu Qifan S288338
Implementation	*Scenario definition*	50%	50%
	Technology modeling	70%	30%
	Analysis of results and post-processing	30%	70%
Writing of the report	*Description of the implemented scenario*	50%	50%
	Description of the technology modeling	70%	30%
	Description of the results	70%	30%
Presentation			