UNIVERSITA' POLITECNICA DELLE MARCHE

FACULTY OF ENGINEERING

Master Degree:

Environmental Engineering

Department of Industrial Engineering and Mathematical Sciences

Airborne pollutant emissions and external costs from road transport: scenarios deriving from SARS-CoV-2 pandemic

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1. INTRODUCTION

Air pollution in our country is one of the main health risks of citizens whose criticalities particularly concern large urban areas; atmospheric emissions from road transport are one of the major sources of air pollution and in urban areas the emission density is very high and is related to population density and flows traffic. For this reason, it was chosen to deepen this argument as the traffic in passenger vehicles and road freight are constantly growing.

Air is a heterogeneous mixture formed by gases and particles of various nature and size. Its composition changes in time and space for causes which may be natural or man-made; it is therefore difficult to define the characteristics of quality. The impossibility of identifying such properties of an uncontaminated environment to which reference, leads to use the term air pollution. The atmosphere is the gaseous envelope that surrounds and dominates a celestial body, whose molecules are held with the gravity of the body itself. The Earth’s atmosphere does not have a homogeneous structure and therefore it is divided into six layers, which starting from the ground are: troposphere, stratosphere, mesosphere, thermosphere, exosphere, and in the mesosphere and thermosphere there is the so-called ionosphere. It arises particular attention to the troposphere, characterized by chemical-physical adequate conditions, it is the place of life, where all the plants and living beings live, that use the gases that constitute it, as well as benefit from the incident solar radiation. It is the place of variations and changes understood as vertical and horizontal that go to stir the atmosphere itself.

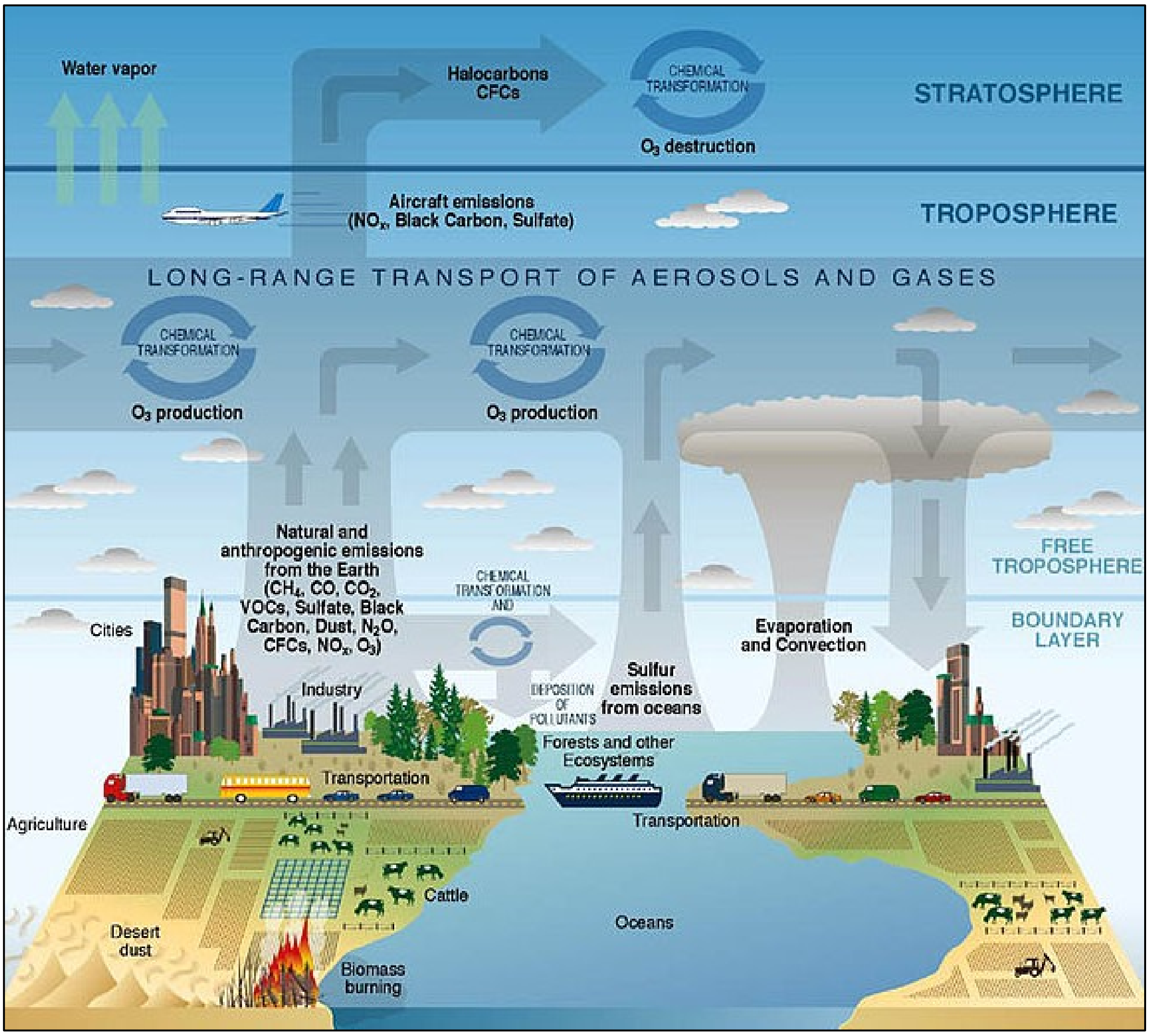

Figure 1 Composition diagram showing the evolution/cycles of various elements in Earth's atmosphere (US CLIMATE CHANGE SCIENCE PROGRAM OFFICE, 2003)

Anthropological activity and industrial development are the main cause the change in optimum atmospheric conditions caused by the introduction into the latter of chemicals, dust or biological materials. This contamination is the air pollution, that is defined as the alteration of the chemical composition of the atmosphere, due to the presence of such substances in concentrations higher than normal in nature, or in the presence of totally different substances, which cause harm or discomfort to humans, from the point of view of health and quality of life, to other living organisms or to the natural environment. Most substances emitted, if natural events such as volcanic eruptions are excluded, arise from human, industrial and transport activities (APAT, 2006).

Air pollution is contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. Household combustion devices, motor vehicles, industrial facilities and forest fires are common sources of air pollution. Pollutants of major public health concern include particulate matter, carbon monoxide, ozone, nitrogen dioxide and sulfur dioxide. Outdoor and indoor air pollution cause respiratory and other diseases and is an important source of morbidity and mortality (World Health Organization, 2021).

A pollutant is a substance that modify the air composition. There are pollutant of different origin: from anthropogenic sources and from natural sources. For substances of natural origin, reference is made to those arising from volcanic eruption phenomena (SO_2), to incendiary sources (PM_{10}) or due to the decomposition of organic compounds (allergens). The causes of man-made pollution are those human activities that have an impact on air, such as vehicular traffic, domestic heating, industrial activities and agriculture. The combination of these, or the direct arrival in the atmosphere of these pollutants, has the effect of altering a stationary situation that modifies the chemical and physical parameters, acting on the quantitative relationships of substances already present and introducing foreign bodies, thus producing polluted air. The latter is considered to have such a composition that exceeds the limits established by law, in order to avoid harmful effects on man, animals, vegetation, materials or ecosystems in general (APAT, 2006).

Figure 2 Example of natural source of air pollution: volcanoes eruption (Abdul Wahab, 2022)

Figure 3 Example of anthropogenic source of air pollution: vehicular traffic (European Commission, 2019)

The distinction between pollutants is of fundamental importance:

- Primary pollutant: they are released into the environment directly as a result of process that originated them, both because of human and natural processes, without undergo further modifications.
- Secondary pollutant: substances formed as a result of modifications of various nature, by chemical-physical reactions between the primary pollutants themselves or with atmosphere, can be activated by solar energy and often involve atmospheric oxygen.

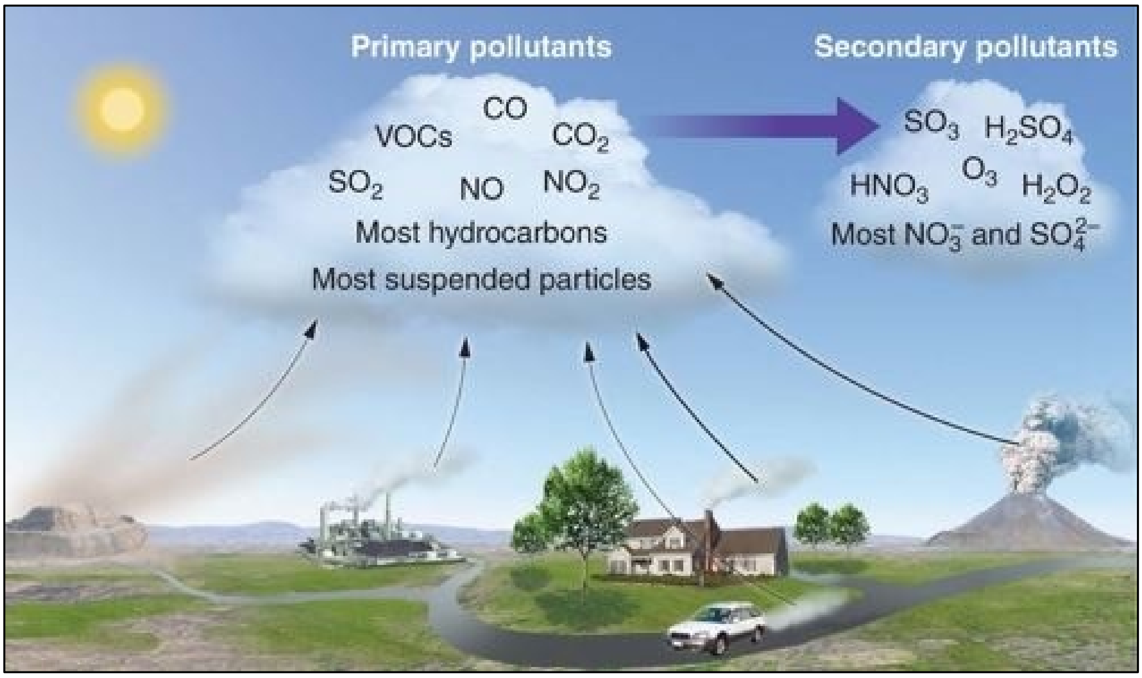

Figure 4 Primary and secondary pollutants

The vehicular traffic constitutes today the main responsible of the atmospheric pollution in urban areas, due to the emission of fuel combustion products and their subsequent chemical transformation, as well as the evaporation of unburnt hydrocarbons (Cattani, 2017).

The pollutants coming from vehicular pollution analyzed for this study are:

- ammonia (NH_3),
- non-methane volatile organic compounds (NMVOC),
- sulfur dioxide (SO_2),
- nitrogen oxides (NO_x),
- particulate matter ($PM_{2.5}$, PM_{10}) and
- carbon dioxide (CO_2).

Ammonia (NH_3) is a corrosive, colorless gas with a distinctive, pungent odor. Commonly found in nature, ammonia can also be stored as a liquid at high pressure and is easily soluble in water. Ammonia deposits itself in wet and dry forms on land, plants, soils, and water. Chemically, ammonia is NH_3 when un-ionized and NH_4^+ when ionized. Ammonia can contribute to the environmentally damaging processes of soil acidification and eutrophication of water bodies. Ammonia in vehicle tailpipe emissions, when combined with nitrogen and sulfur compounds, contributes to smog in major cities. Ammonia is an air pollutant and a secondary particulate precursor. It combines with other compounds in the atmosphere like nitric and sulphate acids to form ammonium salts, a harmful form of fine particulate matter (R., 2015).

Non-methane volatile organic compounds, or NMVOC, is the collective name of a large number of gaseous organic compounds, not including methane, which at a temperature of 293.15° K has a vapour pressure of 0.01 kPa or more. The group includes alcohols, aldehydes and alkanes and examples of substances included in the group are benzene, xylene, propane and butane. NMVOCs are emitted to air at incomplete combustion and by vaporisation. In the past, the transport sector has been an important contributor to national emissions of NMVOCs, but as a result of effective measures the introduction of catalysts) emissions from this sector have decreased substantially. Today, the most important source is evaporation from solvents within the sector product use. Refineries and pulp and paper plants are the largest contributors to national point source emissions. NMVOCs are also emitted to the atmosphere naturally, for example in the form of terpenes from vegetation (such as coniferous trees). NMVOCs, emitted mainly by road transport, as well as paints and solvents, can have a number of damaging impacts on human health. Some have direct toxic effects; benzene and formaldehyde, for example, are known to cause cancer. NMVOCs can also have indirect effects on health by contributing to the formation of ground-level ozone, which causes respiratory and cardiovascular problems (Laurent, 2014).

Sulfur dioxide is a colorless gas that smells strong, suffocating, and pungent. It is the most common form of sulfur oxide. Sulfur dioxide is generated by any industrial activity that uses materials containing sulfur to generate electricity, though it can also be produced by vehicles through fuel combustion. Sulfur dioxide is a precursor to acid rain, which can cause acidification of lakes and soils as well as accelerate the deterioration of buildings. When sulfate particles are combined with other compounds like ammonia, they can become particulate matter, or $PM_{2.5}$. $PM_{2.5}$ impacts the environment in many of the same ways that sulfur dioxide does. Sulfur dioxides are considered indirect greenhouse gases, along with nitrogen oxides, carbon monoxides, and non-methane volatile organic compounds (VOCs). An indirect greenhouse gas has an effect on atmospheric warming through either chemical reaction or changing the Earth’s capability to balance radiative energy (European Environment Agency, 2015).

Nitrogen oxide (NO_x) is a generic term for the nitrogen oxides that are most relevant for air pollution, namely nitric oxide (NO) and nitrogen dioxide (NO_2). These gases contribute to the formation of smog and acid rain, as well as affecting tropospheric ozone. NO_x gases are usually produced from the reaction among nitrogen and oxygen during combustion of fuels, such as hydrocarbons, in air; especially at high temperatures, such as in car engines. In areas of high motor vehicle traffic, such as in large cities, the nitrogen oxides emitted can be a significant source of air pollution. NO_x gases are also produced naturally by lightning. When NO_x and volatile organic compounds (VOCs) react in the presence of sunlight, they form photochemical smog, a significant form of air pollution. The presence of photochemical smog increases during the summer when the incident solar radiation is higher. The emitted hydrocarbons from industrial activities and transportation react with NO_x quickly and increase the concentration of ozone and peroxide compounds, especially peroxyacetyl nitrate (PAN) (Peter., 2000) (United States Environmental Protection Agency, 2007).

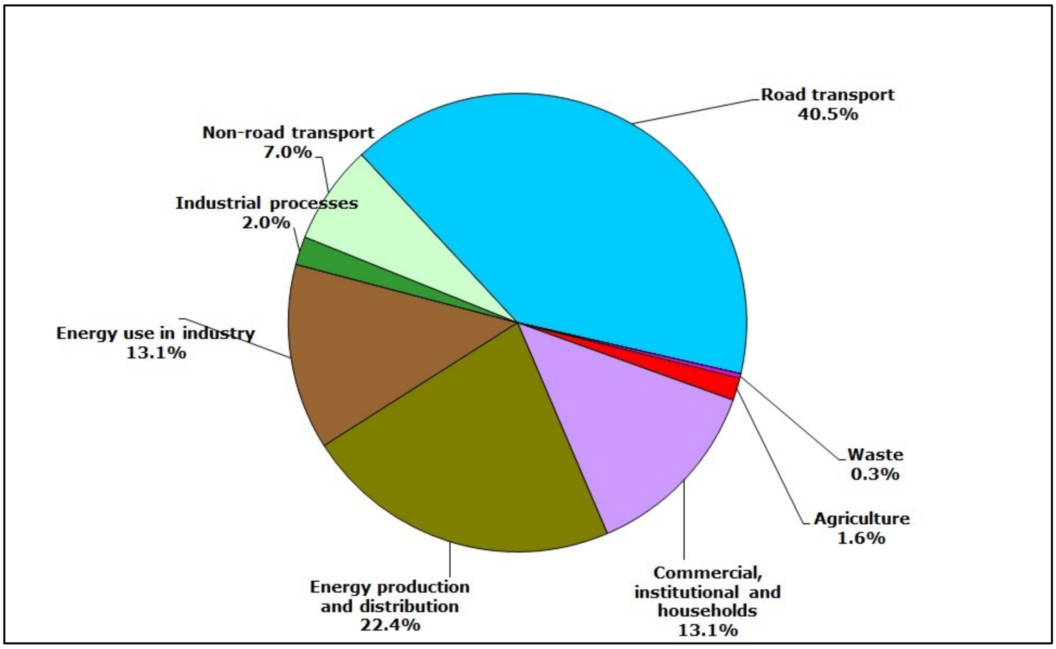

Figure 5 Contribution of sectors to emission of NOx (United Nations Economic Commission for Europe (UNECE), 2010)

Particulate matter, or PM, refers to particles found in the air, including dust, soot, dirt, smoke, and liquid droplets. $PM_{2.5}$ particles measure 2.5 microns or less in diameter. $PM_{2.5}$ particles are so small they can only be seen with an electron microscope. Of all air pollution measures, $PM_{2.5}$ poses the greatest health threat. Due to its small size, $PM_{2.5}$ can remain suspended in the air for long periods of time and can be absorbed deep into the bloodstream upon inhalation. Particulate matter can be either emitted directly from manmade or natural sources, with manmade sources generally resulting in greater amount of $PM_{2.5}$. Some of the most common manmade sources of $PM_{2.5}$: motor combustion, power plant combustion, industrial processes stoves, fireplaces and home wood burning, smoke from fireworks smoking. $PM_{2.5}$'s microscopic size increases its potential to be lodged deep into the respiratory tracts. At 2.5 microns, $PM_{2.5}$ is capable of entering the circulatory system and even the brain.9 Short term symptoms of exposure to high levels of particulate matter include irritation of the throat and airways, coughing, and difficulty breathing. $PM_{2.5}$ causes environmental harm in several ways, such as: damage of materials and buildings, acid deposition, increased ozone levels. $PM_{2.5}$ can travel long distances through strong winds, up to hundreds of thousands of miles from their source. $PM_{2.5}$ can be carried to coastal waters and river basins, where they change the nutrient balance. When particle pollution settles on crops and forests, it can damage the vegetation (Department for Environment Food & Rural Affairs, 2016) (Environmental Protection Agency, Ireland., 2020) (Environmental Protection Agency, 2020).

PM_{10} is suspended coarse particulate matter, either solid or liquid, with a diameter of 10 micrometers (µm) or less. Particulate matter is sometimes referred to as floating dust or aerosols. Fine particles can remain suspended in the atmosphere from days to weeks, allowing the materials to travel over long distances. Larger particles are soon returned to the surface due to precipitation and gravity. PM_{10} is any particulate matter in the air with a diameter of 10 micrometers or less, including smoke, dust, soot, salts, acids, and metals. Particulate matter can also be formed indirectly when gases emitted from motor vehicles and industries undergo chemical reactions in the atmosphere. Health effects of PM_{10} exposure can vary. The body tends to eliminate larger particles, while $PM_{2.5}$ can stay embedded in the lungs. However, both $PM_{2.5}$ and PM_{10} harm human health. PM_{10} reduces visibility and, in some cases, can corrode organic and inorganic materials from vegetation to buildings. Painted surfaces, stone, fabrics, metal, and wood can become damaged and discolored. When particulate matter is deposited on vegetation and soils, it can leach nutrients and increase the chances plants succumb to disease (California Air Resources Board, 2020).

Carbon dioxide (CO_2) is a colorless, odorless gas formed from carbon and oxygen atoms. The fourth most common gas found in the earth's atmosphere next to nitrogen, oxygen, and argon, CO_2 can also be liquid or solid. In its solid form, CO_2 is known as dry ice. Carbon dioxide a natural part of the Earth's carbon cycle, which is the circulation of carbon between the atmosphere, plants, animals, soils, and oceans. Humans, animals, fungi, and microorganisms produce CO_2 and plants absorb it. However, human activity since the industrial era has significantly increased levels of CO_2 and altered this cycle, decreasing the ability of natural carbon sinks like forests to remove it from the atmosphere. Carbon dioxide is now best known as the primary greenhouse gas emitted through human activity. Human-made carbon dioxide is primarily produced through burning fossil fuels such as oil, coal, and natural gas. Some main sources of emissions globally include transport, industry, and fuel burning for electricity and heating. Carbon dioxide can build up indoors if rooms are not well-ventilated. Carbon dioxide is also produced through natural sources such as animals, volcanoes, oceans, soils, and decaying plants. Though relatively nontoxic and noncombustible, CO_2 can pose a number of serious health concerns. Higher concentrations (>5000ppm over a few hours) can provoke increased heart rate, elevated blood pressure, or, in extreme cases, coma, asphyxia, and convulsions. Prolonged lack of oxygen can also permanently damage organs, including the heart and brain. As the primary greenhouse gas contributing to global warming and climate change, CO_2 bears significant environmental impacts. CO_2 is a 'heat-trapping' gas, in that it limits the heat radiation that reaches the Earth from being reflected back away again. CO_2 and other greenhouse gases contribute to the "greenhouse effect", trapping more and more heat in the Earth's atmosphere instead of reflecting the heat away (Wisconsin Department of Health Services, 2019) (Canadian Center for Occupational Health and Safety, 2017).

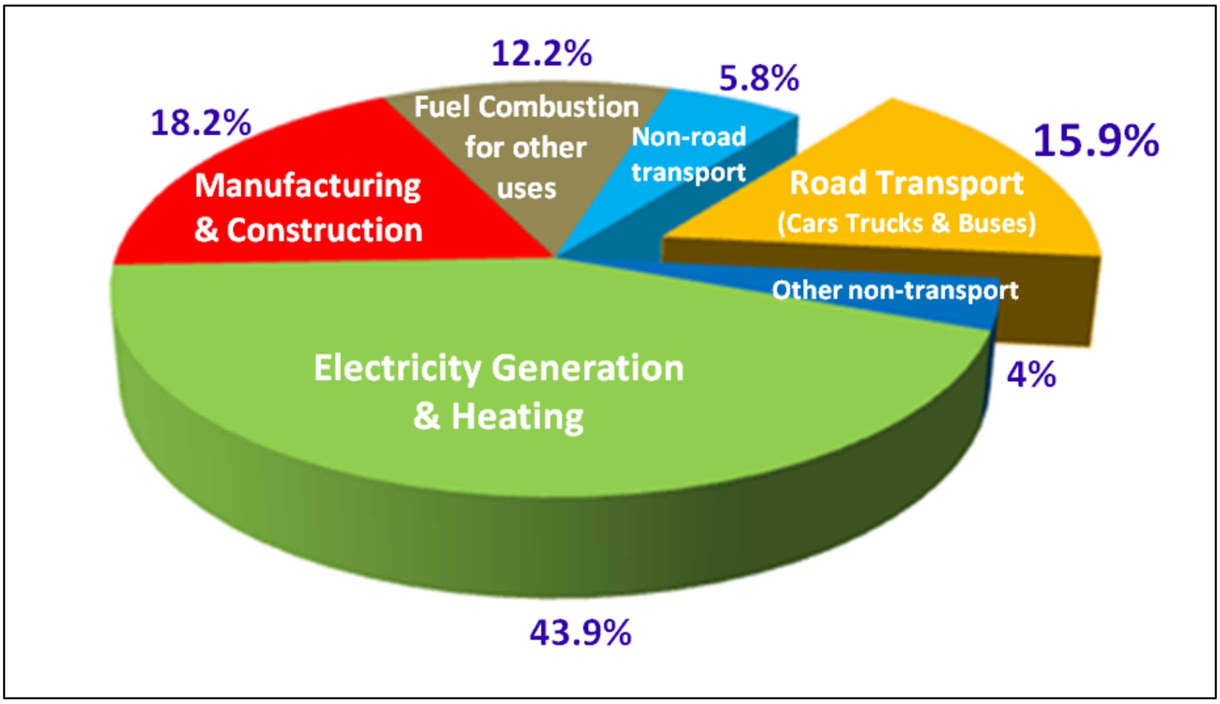

Figure 6 Man-made CO_2 emissions (International Organization of Motor Vehicle Manufacturers, s.d.)

With reference to the aim of this thesis work the incidence of Covid-19 to the air pollution will be analyzed. The Covid-19 is a coronavirus identified in 2019, SARS-CoV-2, that has caused a pandemic of respiratory illness. On 11 March 2020, the WHO director-general declared the global Covid-19 pandemic (World Health Organization, 2020a). Over 2020, the disease was spreading all over the world with more than 103 million cases, and more than 2.2 million people passed away as of January 30th, 2021 (Johns Hopkins Coronavirus Resource Center (JHCRC), 2020). The primary transmission of the Covid-19 is identified as to be exposed to respiratory air droplets and to touch common surfaces (World Health Organization, 2020b).

Transportation is related to the global spread of the diseases. Some transportation modes provide a risky environment due to the exposure of staying in a limited space for a long period of time without social distancing; moreover, common surfaces are touched. Therefore, the relationship between transportation and global diseases is examined in the literature as well as it is investigated how travel behavior is affected. Following these, understanding the impacts of a pandemic on travel demand is of paramount importance to draft future transport planning and policies. The COVID-19 pandemic has produced several unprecedented effects around the world and has adversely affected the transport sector, which has experienced a drastic reduction in passenger traffic across all different modes of transport.

Isfort's "Audimob Observatory" carries out continuous sample surveys on the mobility of Italians (age 14-80 years), through telephone and computer interviews. It is therefore possible, within the limits of a partial survey, to estimate the trend of daily mobility behaviour of citizens restrictions due to the health emergency from Covid-19 (ISFORT, 2020).

If in the two-year period 2017-2019 there was a recovery in demand mobility (+8% travel, +14% passengers*km), after a phase of almost ten years of contraction from the economic crisis of 2008 onwards, the figure of 2020 is undoubtedly given by the expected vertical collapse of mobility during lockdown, estimated in the order of 67% less daily travel and 84% less passengers*km. Demand rebounding since the first post-restriction phase was very vigorous and then maintained in the following months (+156% for travel, +352% for passengers*km between mid-May and mid-October), however pre-October levels Covid of 2019 are still distant of approximately 15% for the number of travels and of approximately 25% for the number of passengers*km (ISFORT, 2020).

During the lockdown period (12 March - 3 May) there was a predictable vertical drop in demand volumes compared to the pre-Covid-19 ordinary regime (reference to the 2019 average), estimated at over 65% less daily travel and over 80% less passengers*km. On the drastic reduction of the distances has affected, besides the strong decrease of the distances daily per capita, also reducing the average travel length (about the 40%), the obvious and predictable effect of the "proximity-only displacement rule, unless justified exceptions are made" during confinement. At the same time the mobility rate has decreased from 85% of the 2019 average to 32% of closing period, but if shorter walking distances are also considered (less than 5 minutes), the reduction of what can be called the "increased mobility rate" was in lower proportion, from 91% to 49%. How overall assessment is therefore confirmed that the Italians have complied with the rules of restriction (vertical drop in demand), without, however, being completely crushed at home confinement. In general, the impact of lockdown has been much higher on the behaviors of the bands older people who expressed a real mobility rate during the period reduced (16%). Also the decline in the demand for mobility of young people and very young, due to the total closure of schools, was higher than average. The rate of mobility has also recorded a particularly marked decline in Regions of Central Italy (-56% against the national average of -48%), more content instead to the South and the Islands (-43%), while the territories of the North, where the days are affected restrictions prior to 12 March, when the mobility rate had already started descent, in Lombardy and in several other northern provinces, are placed little below the national average. There does not seem to be a specific correlation the evolution of the index compared to the size of the municipalities of residence of interviewed (ISFORT, 2020).

In the weeks following the full removal of travel, the demand for mobility of citizens has experienced, according to estimates of "Audimob", a very strong leap forward. It is not a surprising dynamic, either the full reopening of economic and social activities (with some exception), both for a reasonable psychological reaction to the long months of confinement. The rebound in demand then stabilized in the following months which were monitored (until 15 October) (ISFORT, 2020).

2. DATA AND CALCULATIONS

2.1 DATA AND METHODS

The first part of this work is related to the development of proxy values determined by the extent of roads and the population. For a detailed list of roads it is important to refer to the Automobile Club Italia. The “Automobile Club Italia” (also known as RACI until 1946 and later ACI) is a non-economic public body of the Italian Republic. ACI’s action is aimed at promoting motoring, protecting the general interests of motoring, defining regional planning, providing education and education in the field of mobility, managing, by delegation of the State, the Public Register of Motor Vehicles, and promote motor sport. In addition to providing services to its members, by virtue of a public body, the ACI also operates for the benefit of the community. With regard to its public nature, the ACI carries out numerous institutional activities and is responsible for the provision of services to the community. Among the most important are the management of the Public Register of Automobiles, of the regional automotive taxes and of the regional tax of transcription. The ACI periodically conducts studies on the development of the local vehicle park, with international or regional estimates and comparisons. The studies and research section includes statistical publications on the phenomenon of the motor vehicle as a whole: vehicle fleet and market trends, incidentality; annual archive on circulation and market trends.

The “Automobile Club Italia” has developed a database with a detailed list of extra-urban roads divided by type. This study analyses the provision of road infrastructure throughout the Italian territory updated to 2011 at regional level and with provincial detail and provides a summary for geographical areas. A first reading of the available data evidences a presence of freeways and assimilated pairs to approximately 7.150 kilometers of extended (4.6% regarding the total), percentage that but introduces a strong variability in the within of the national territory in decreasing modality from north to south: It goes from a value of 6.4% in North-Western Italy (almost 2,000 kilometers) to a value of 3% in Insular Italy (700 kilometers of roads). Taking into consideration the individual provinces, deserves a report the value of Monza and Brianza, equal to 52%, which is by far the highest in the national territory. As for the roads of national interest, equal to over 20,000 kilometers of extended (13.2% of the total), there is an inverse process compared to the previous case of the Highways: in the North and in Central Italy in fact the percentages are between 7% and 8% of the roads of competence of the respective Geographic Areas (little more than 2.000 kilometers for North-West and North-East Italy, almost 2.500 kilometers for Central Italy)and then increase considerably in the South (17%, equal to almost 7,000 kilometers) and especially in the Islands (6,800 kilometers of extended, equal to 29% of roads in that territory). There are, however, exceptions according to which some provinces differ significantly, and often in contrast, from the value of the Geographical Area to which they belong; specifically, as regards Northern Italy-We point out the provinces of Verbania (25% of roads of national interest compared to the extensive provincial total), Monza and Brianza (48%) and Sondrio (39%), while for the Islands we report the provinces of Ragusa and Syracuse, both with a value of 16% (Automobile Club d'Italia, 2011).

For each province, the number of inhabitants has been reported, referring to ISTAT data. The Italian National Institute of Statistics, a public research organization, is the main producer of official statistics in the service of citizens and policy makers. It operates in complete independence and continuous interaction with the academic and scientific communities (ISTAT, 2020).

Tables from Table 1 to Table 21 show the different roads (highways, national roads, regional roads, provincial roads, roads to be classified) and the population for each province of each region of Italy.

PIEMONTE							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Alessandria	181			2129		2310	411922
Asti	45	12		1312	7	1376	209648
Biella				708	6	715	171838
Cuneo	119	245		3300	19	3683	582353
Novara	103	59		778	16	957	362199
Torino	301	157		2766		3224	2212996
Verbania	18	186		538		741	155065
Vercelli	101			981		1083	167189
Total Piemonte	867	659		12512	49	14088	4273210

Table 1 Roads and population of each province of Piemonte region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

VALLE D'AOSTA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Aosta	109	153	500			762	123895
Total Valle D'Aosta	109	153	500			762	123895

Table 2 Roads and population of each province of Valle D'Aosta region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

LOMBARDIA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Bergamo	32	46		1036	280	1394	1099621
Brescia	130	155		1352	215	1852	1247583
Como	23	97		548		668	594671
Cremona	18			631	246	895	351698
Lecco		72		469		541	332593
Lodi	39	52		449		541	225885
Mantova	38	20		827	295	1180	403585
Milano	165	100		688	116	1069	3249821
Monza e Brianza	24	22				46	867421
Pavia	95	7		1730	326	2158	534951
Sondrio		238		367		606	179234
Varese	46	174		605	68	894	879929
Total Lombardia	609	986		8702	1545	11842	9966992

Table 3 Roads and population of each province of Lombardia region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

TRENTINO ALTO ADIGE							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Bolzano	116			1234	823	2173	533715
Trento	70			1510	884	2465	544745
Total Trentino Alto Adige	186			2744	1707	4638	1078460

Table 4 Roads and population of each province of Trentino Alto Adige region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

VENETO							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Belluno	16	217	205	709		1147	199599
Padova	74	87	167	1093		1421	929520
Rovigo	25	82	124	546		777	229652
Treviso	100	80	152	1276		1608	878070
Venezia	107	126	129	879		1242	842942
Verona	137	137	199	1504		1978	922291
Vicenza	72	47	64	1266		1449	850379
Total Veneto	530	777	1041	7273		9621	4852453

Table 5 Roads and population of each province of Veneto region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

FRIULI VENEZIA GIULIA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Gorizia	38	17	87	128	7	276	136809
Pordenone	32		229	650	32	943	309058
Trieste	30	22	34	135	8	229	229470
Udine	151	106	605	1270	3	2135	523416
Total Friuli Venezia Giulia	250	145	954	2183	50	3582	1198753

Table 6 Roads and population of each province of Friuli Venezia Giulia region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

LIGURIA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Genova	147	138		1037		1322	816916
Imperia	61	129		788	6	985	208585
La Spezia	64	78		631		773	215538
Savona	105	99		777	17	998	268766
Total Liguria	378	445		3233	24	4079	1509805

Table 7 Roads and population of each province of Liguria region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

EMILIA ROMAGNA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Bologna	172	153		1134	16	1475	1019539
Ferrara	77	97		933		1107	341967
Forlì-Cesena	43	181		1075	15	1315	393556
Modena	51	165		1004	41	1260	704672
Parma	94	92		1335	31	1552	453604
Piacenza	92	107		1102	7	1309	284075
Ravenna	48	162		817		1028	386309
Reggio Emilia	40	110		1125	18	1293	526349
Rimini	30	56	48	433		566	335478
Total Emilia Romagna	648	1123	48	8958	127	10904	4445549

Table 8 Roads and population of each province of Emilia Romagna region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

TOSCANA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Arezzo	70	125	184	1062	1	1441	336870
Firenze	129	98	322	1086	2	1637	986001
Grosseto		156	122	1708		1986	218538
Livorno	34	96	67	517		715	329590
Lucca	67	69	110	515		761	380676
Massa Carrara	57	99	15	643	11	825	189841
Pisa	42	80	203	823		1147	416425
Pistoia	29	62	87	393		571	290819
Prato	10		4	73		87	256047
Siena	61	92	206	1477		1837	263526
Total Toscana	497	878	1321	8298	14	11008	3668333

Table 9 Roads and population of each province of Toscana region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

UMBRIA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Perugia	48	396	777	1958		3180	643311
Terni	46	141	235	657	3	1081	221702
Total Umbria	94	537	1012	2615	3	4261	865013

Table 10 Roads and population of each province of Umbria region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

MARCHE							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Ancona	56	139		974		1170	465023
Ascoli Piceno	44	39		959		1041	204575
Fermo	28	27		856		912	170248
Macerata	19	106		1505		1629	307421
Pesaro Urbino	43	146		1644		1833	354139
Total Marche	190	457		5938		6585	1501406

Table 11 Roads and population of each province of Marche region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

LAZIO							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Frosinone	84	4	484	1562	29	2162	473467
Latina		149	264	938		1351	561139
Rieti	29	119	299	1129		1576	151668
Roma	332	160	393	1968	18	2870	4227588
Viterbo	29	122	168	1360		1679	306934
Total Lazio	473	553	1608	6958	47	9639	5720796

Table 12 Roads and population of each province of Lazio region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

ABRUZZO							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Chieti	89	215		1786	8	2097	376397
L'Aquila	131	433	562	1259		2385	292356
Pescara	58	104		791	1	955	314689
Teramo	89	238		1627	21	1975	301814
Total Abruzzo	366	991	562	5463	31	7413	1285256

Table 13 Roads and population of each province of Abruzzo region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

MOLISE							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Campobasso	36	351		1254	3	1643	214629
Isernia		232			856	1088	81918
Total Molise	36	583		1254	859	2731	296547

Table 14 Roads and population of each province of Molise region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

CAMPANIA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Avellino	110	275		1330	191	1906	405963
Benevento	11	190		1270	10	1482	269233
Caserta	71	242		1502		1816	911606
Napoli	119	128	64	542	90	944	3017658
Salerno	193	475	455	2079		3202	1075299
Total Campania	504	1310	520	6724	291	9350	5679759

Table 15 Roads and population of each province of Campania region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

PUGLIA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Bari	78	251		1565		1893	1222818
Barletta-Andria-Trani	44	131		584		759	382685
Brindisi		136		927		1063	382454
Foggia	170	636	20	2741	2	3569	601419
Lecce		236		2196		2432	777507
Taranto	23	212		1191	108	1533	560048
Total Puglia	314	1602	20	9204	110	11250	3926931

Table 16 Roads and population of each province of Puglia region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

BASILICATA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Matera		352			1412	1764	193457
Potenza	65	709			363	1137	354122
Total Basilicata	65	1061			1775	2902	547579

Table 17 Roads and population of each province of Basilicata region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

CALABRIA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Catanzaro	47	264		1280		1591	346514
Cosenza	138	621			6	766	684786
Crotone		119		826		945	166617
Reggio Calabria	78	242		1351	7	1679	526586
Vibo Valentia	36	106		724	144	1010	153225
Total Calabria	300	1352		4182	157	5991	1877728

Table 18 Roads and population of each province of Calabria region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

SICILIA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Agrigento		563		879	5	1447	419847
Caltanissetta	14	366		1147		1527	252803
Catania	95	489		1315	12	1911	1066765
Enna	66	444	73	784	6	1373	158183
Messina	197	482		1423		2102	609223
Palermo	172	753	102	1598		2624	1214291
Ragusa		141	89	638		868	314950
Siracusa	58	247	122	1056	70	1554	386451
Trapani	124	332		849	6	1311	418363
Total Sicilia	725	3819	386	9687	100	14717	4840876

Table 19 Roads and population of each province of Sicilia region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

SARDEGNA							
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
Cagliari		562		929		1490	420117
Nuoro		774		1017	192	1983	202951
Oristano		303		900		1203	153226
Sassari		1029		2101	35	3165	481052
Sud Sardegna		323		640		963	340879
Total Sardegna		2990		5586	227	8803	1598225

Table 20 Roads and population of each province of Sardegna region (Automobile Club d'Italia, 2011) (ISTAT, 2020)

ITALY							
Area	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population
North-West Italy	1963	2244	500	24448	1617	30771	15873902
North-East Italy	1614	2045	2043	21158	1884	28745	11575215
Central Italy	1255	2425	3941	23809	64	31493	11755548
South Italy	1586	6900	1102	26826	3223	39637	13613800
Insular Italy	725	6809	386	15273	327	23520	6439101
Total Italy	7143	20423	7971	111514	7115	154166	59257566

Table 21 Roads and population of Italy and each area of Italy (Automobile Club d'Italia, 2011) (ISTAT, 2020)

From the Eurostat site it is possible to find the number of passengers per kilometers for different modes of transport for the year 2019. Eurostat is the statistical office of the European Union. Its mission is to provide high quality statistics and data on Europe and Eurostat coordinates statistical activities at Union level and more particularly inside the Commission.

Passenger mobility refers to the movement of people using any kind of motorised, non-motorised, collective or individual means of transportation. Mobility represents a key economic driver as moving people is a pre-requisite for several activities and is therefore at the core of a well-functioning and prosperous society. Raising the efficiency and quality of a country's mobility infrastructure strengthens the economy and increases the standard of living for its citizens.

Table 22 shows the millions of passengers per kilometer for the private mobility including motorcycles and passenger cars and the public mobility including motor coaches, buses and trolley buses. The value of passenger per kilometer indicates the transport of one passenger by a defined transport mode of transport per one kilometer (EUROSTAT, 2019).

Vehicles	Millions of passenger-km 2019 in Italy
Motorcycles	39189
Passenger cars	732429
Private mobility (motorcycles + passenger cars)	771618
Public mobility (motor coaches, buses and trolley buses)	102934
Total (private mobility + public mobility)	874552

Table 22 Millions of passenger-km for different mode of transport (EUROSTAT, 2019)

Private mobility is composed by passenger cars contribution that accounts for the 95% of the total private mobility and by motorcycles contribution that account for the 5%. Public mobility is composed by the contribution of motor coaches, buses and trolley buses. Taking into consideration the total mobility that includes the private mobility and the public mobility, it is possible to determine the contribution in percentage of the private mobility that is 88% and the contribution of public mobility that is 12% of the total mobility.

2.1.2 EXTERNAL COSTS OF ROAD TRANSPORT

In order to determine the costs of transport, the Handbook on external costs of 2019 has been analyzed. The report provides an overview of the methodologies and input values that can be used to provide state of the art estimates for all main external costs of transport. The objective of this Handbook is to provide information on how to generate state-of-the-art estimates for all main external costs of transport. This information is provided at three levels:

- Methodological level
- Input values
- Output values.

In this Handbook, state of the art methodologies, input values and output values for total, average and marginal external costs of transport are provided, both at the EU28 level as at the level of individual countries. This is done for all transport modes and all (main) external cost categories.

Furthermore, the report and corresponding excel file present the total, average and marginal external costs for all relevant countries. Total external costs refer to all external costs within a geographical boundary caused by a specific mode of transport. Total external costs are usually presented in billions or millions Euros. Average external costs are closely related to total costs, as they express the costs per transport performance. In this study average external costs are generally presented in €-cent/pkm (Van Essen et al., 2019).

This document covers all main externalities of transport:

- accidents;
- air pollution;
- climate change;
- noise;
- congestion;
- well-to-tank emissions;
- habitat damage.

Accidents occur in all forms of traffic and result in substantial costs, consisting of two types of components: material costs (damages to vehicles, administrative costs and medical costs) and immaterial costs (shorter lifetimes, suffering, pain and sorrow). There are five main components of accident costs:

- Human costs: This is a proxy for estimating the pain and suffering caused by traffic accidents in monetary value. In cases of injuries it covers the victim’s pain and suffering, in cases of fatalities it covers the victim’s loss of utility. Traffic participants are assumed to be aware of the fact that their decision to enter the traffic may result in an accident (they internalise this risk). Therefore, their own human costs are considered internal to them, once they have made the decision to enter the traffic. However, they consider the human costs of others that may result from their own transport decision as external to them.

- Medical costs: These are the costs of the victim’s medical treatment provided by hospitals, rehabilitation centres, general practitioners, nursing homes, etc. as well as the costs of appliances and medicines. The medical costs cover the time period from the moment of the accident until complete recovery from the injury or, in the case of fatal accidents, death. In many cases a part of these costs is already internalized through health insurance premiums.

- Administrative costs: These are the costs covering the expenses of the deployed police force, fire service and other emergency (non-medical) services that assist at the crash location site. In addition, costs related to the administration of justice such as legal costs, the costs of prosecution of offenders and the costs of lawsuits and insurance are incorporated into this category. Lastly, administrative costs related to vehicle, health or other insurance is also included in this category. This component is assumed to be partly internalised by traffic participants in the form of insurance.

- Production losses: After an accident victims are not directly capable of returning to work, and in some cases may never return to work. These costs consists of the net production losses due to reduced working time and the human capital replacement costs. Not being able to carry out non-market work such as household work or volunteering is also incorporated in this cost component. This component is assumed to be partly internalised by traffic participants in the form of insurance.
- Material damages: This consists of the monetary value of damages to vehicles, infrastructure, freight and personal property resulting from accidents. This component is assumed to be fully internalised by traffic participants through insurance.

Air pollution costs are one of the external cost categories that has been analysed the most. Since the nineties a broad range of international studies and research projects have been conducted, particularly on European level. In the last few years, there haven't been many large international studies covering the entire impact pathway from emission to impact and costs. However, epidemiological research has carried on, investigating the dose-response-relationship between the exposure of air pollutants and the associated health risks. The Handbook covers the following four types of impacts caused by the emission of transport related air pollutions:

- Health effects: The inhalation of air pollutants such as particles (PM10, PM2.5) and nitrogen oxides (NOx) leads to a higher risk of respiratory and cardiovascular diseases (bronchitis, asthma, lung cancer). These negative health effects lead to medical treatment costs, production loss at work (due to illness) and, in some cases, even to death.

- Crop losses: Ozone as a secondary air pollutant (mainly caused by the emission of NOx and VOC) and other acidic air pollutants (SO2, NOx) can damage agricultural crops. As a result, an increased concentration of ozone and other substances can lead to lower crop yields.

- Material and building damage: Air pollutants can mainly lead to two types of damage to buildings and other materials: a) pollution of building surfaces through particles and dust; b) damage of building facades and materials due to corrosion processes, caused by acidic substances (nitrogen oxides NOx or sulphur oxide SO2).

- Biodiversity loss: Air pollutants can lead to damage to ecosystems. The most important damages are a) the acidification of soil, precipitation and water (by NOx, SO2) and b) the eutrophication of ecosystems (by NOx, NH3). Damages to ecosystems can lead to a decrease in biodiversity (flora & fauna).

Climate change costs are defined as the costs associated with all of the effects of global warming, such as sea level rise, biodiversity loss, water management issues, more and more frequent weather extremes and crop failures. Due to the fact that the effects of climate change are global, long-term and have risk patterns that are difficult to anticipate, identifying the costs associated with these effects is extremely complex. Transport results in emissions of CO_2, N_2O and CH_4 (methane), all of which are greenhouse gases contributing to climate change. Therefore, identifying the climate costs of transport is extremely important.

Traffic noise is generally experienced as a disutility and is accompanied by significant costs. Noise emissions from traffic pose a growing environmental problem due to the combination of a trend towards greater urbanisation and an increase in traffic volumes. Whilst the increase in traffic volume results in higher noise levels, the increase in urbanisation results in a higher number of people experiencing disutility due to noise. As a result, the costs of traffic noise are expected to grow in the future despite potential noise-reducing improvements in vehicles, tyres and roads. The exposure to noise results in a number of health endpoints due to prolonged and frequent exposure to transport noise.

Congestion is defined as a condition where vehicles are delayed when travelling. In particular, a congestion cost arises when an additional vehicle reduces the speed of the other vehicles of the flow and hence increases their travel time. Road congestion cost can be defined on the basis of a speed-flow relationship in a given context, for example at an urban or inter-urban level. This approach cannot be expanded to other transport modes, like rail and air, as they essentially provide scheduled services and are planned on the basis of the allocative capacity of networks and nodes.

The cost of well-to-tank emissions (costs of energy production) includes the production of all different type of energy sources which leads to emissions and other externalities. The extraction of energy sources, the processing (refining or electricity production), the transport and transmission, the building of energy plants and other infrastructures: all these processes lead to emission of air pollutants, greenhouse gases and other substances. The emissions during the production of energy sources are very relevant in terms of total external costs. Mainly for electricity driven transport modes, the effects of energy production are very relevant since the energy use is virtually emission-free.

For what concerns the habitat damage, the different negative effects of transport on nature and landscape can be described as the following:

- Habitat loss: Transport infrastructure requires land and/or natural surfaces. Therefore, transport infrastructure also leads to a loss of natural ecosystems, which are natural habitats of plants and animals. The land use of transport therefore leads to a loss of habitats (ecosystems), which has a negative effect on biodiversity. Habitat loss is occurring during the building phase of transport infrastructure, but it will last over the whole lifetime of the infrastructure.
- Habitat fragmentation: Transport infrastructure can also have additional fragmentation and separation effects for animals. These fragmentation effects can negatively affect the natural habitats of certain species and lead to adverse effects for species and consequently on biodiversity. Habitat fragmentation due to transport infrastructure is a consequence of the infrastructure itself plus the transport demand on the infrastructure. The main negative effects are caused by large and broad main infrastructures such as motorways and high-speed rail lines. Large wildlife mammals such as deer, rabbit, badger, etc. as well as smaller animals such as amphibians are negatively affected by habitat fragmentation.

- Habitat degradation due to emissions: Habitat degradation can also occur via the emission of air pollutants of other toxic substances (heavy metals, PAH). These effects again lead to biodiversity loss and therefore external costs (Van Essen et al., 2019).

Table 23 and Table 24 refer to total external costs and average external costs for each type of category in Europe. The total external costs are expressed in billion euro and the average external costs in cent per pkm (passenger per kilometer). The passenger-kilometer is the transport of one passenger by a defined mode of transport over one kilomteter.

Total external costs				
Category	Passenger car	Bus	Coach	Motorcycle
	Billion €	Billion €	Billion €	Billion €
Accidents	210.2	5.3		21
Air Pollution	33.4	1.4	2.7	1.8
Climate	55.6	0.8	1.6	1.5
Noise	26.2	0.8	0.9	14.8
Congestion	196.1	4.5		
Well-to-Tank	18.1	0.3	0.5	0.8
Habitat damage	25.9	0.2	0.4	0.5
Total for Transport mode	565.5	19.4		40.4
Total	625.3			

Table 23 Total external costs in Europe for each category and each transport mode (Van Essen et al., 2019)

Average external costs				
Category	Passenger car	Bus	Coach	Motorcycle
	cent per pkm	cent per pkm	cent per pkm	cent per pkm
Accidents	4.5	1	1	12.7
Air Pollution	0.3	0.8	0.7	1.1
Climate	1.2	0.5	0.4	0.9
Noise	0.5	0.4	0.2	9
Congestion	4.2	0.8	0.8	
Well-to-Tank	0.4	0.2	0.1	0.5
Habitat damage	0.5	0.1	0.1	0.3
Total for Transport mode	11.6	3.7	3.5	24.5

Table 24 Average external costs in Europe for each category and each transport mode (Van Essen et al., 2019)

Since passenger car and motorcycle are defined as transport modes of private mobility and bus and coach are defined as transport modes of public mobility, it is possible to group them in order to have the private and the public mobilities for each category of external costs. Table 25 shows the average external costs of each category for private and public mobility.

Average external costs		
Category	Private mobility	Public mobility
	cent per pkm	cent per pkm
Accidents	17.2	2
Air Pollution	1.4	1.5
Climate	2.1	0.9
Noise	9.5	0.6
Congestion	4.2	1.6
Well-to-Tank	0.9	0.3
Habitat damage	0.8	0.2
Total for Transport mode	36.1	7.2

Table 25 Average external costs for each mobility and each category in Europe (Van Essen et al., 2019)

To have a better detail about air pollution costs and climate change costs the Handbook on the external costs of transport shows the costs referred to Italy for each pollutant. In particular for air pollution the pollutants NH_3, NMVOC, SO_2, NO_x (transport city), $PM_{2.5}$ (transport city), PM_{10} average have been analyzed; for climate change the pollutant CO_2 has been analyzed. The Handbook provides the values of the average costs (expressed in euro per kilogram) for each pollutant in Italy for both air pollution and climate change costs.

Table 26 and Table 27 show these values (Van Essen et al., 2019).

AIR POLLUTION COSTS-AVERAGE COST IN €/Kg EMISSION IN ITALY					
NH_3	NMVOC	SO_2	NO_X (transport city)	$PM_{2.5}$ (transport city)	PM_{10} (average)
21.6	1.1	12.7	25.4	132	27

Table 26 Average air pollution costs in Italy (Van Essen et al., 2019)

CLIMATE CHANGE COSTS IN €/Kg
CO_2
0.1

Table 27 Average climate change costs in Italy (Van Essen et al., 2019)

Furthermore, the Handbook provides the average external costs expressed in euro-cent per pkm related to each country. In particular here the values referred to Italy are reported. Tables from Table 28 to Table 33 show the average external costs in Italy related to accident, air pollution, climate change, noise, well to tank and habitat damage.

Average accident costs (euro-cent per pkm)	
Private mobility	Public mobility
4.4	0.5

Table 28 Average accident costs for transport mode in Italy (Van Essen et al., 2019)

Average air pollution costs (euro-cent per pkm)	
Private mobility	Public mobility
0.738	0.78

Table 29 Average air pollution costs for transport mode in Italy (Van Essen et al., 2019)

Average climate change costs (euro-cent per pkm)	
Private mobility	Public mobility
1.128	0.409

Table 30 Average climate change costs for transport mode in Italy (Van Essen et al., 2019)

Average noise costs (euro-cent per pkm)	
Private mobility	Public mobility
0.9	0.69

Table 31 Average noise costs for transport mode in Italy (Van Essen et al., 2019)

Average well to tank costs (euro-cent per pkm)	
Private mobility	Public mobility
0.393	0.177

Table 32 Average well to tank costs for transport mode in Italy (Van Essen et al., 2019)

Average habitat damage costs (euro-cent per pkm)	
Private mobility	Public mobility
0.4	0.1

Table 33 Average habitat damage costs for transport mode in Italy (Van Essen et al., 2019)

2.1.3 EMISSION ANALYSIS

The term emission means any solid, liquid or gaseous substance introduced into the atmosphere which may cause air pollution. The emission source can be, for example, a production plant or motor traffic that flows along roads. If the emission source is localized, it is possible to speak of punctual emission (typical example is an industrial chimney), linear (a stretch of road to which are associated the emissions of the motor vehicles that run through it) or areal (a tank from which evaporates a certain pollutant). If, on the other hand, the gaseous effluent is not emitted through one or more chimneys, it is generally referred to as diffuse emissions. The total emission is the sum of diffuse emissions and channeled emissions. Emission sources may also be classified as continuous or discontinuous according to the mode of "operation" over time (during the year), and fixed (an electrical power generation plant) or mobile (certain machines used in agriculture) depending on their location in space (ARPAV, 2014).

The emission factor represents the emission referred to the unit of activity of the source, expressed for example as the amount of pollutant emitted per unit of processed product, or as the amount of pollutant emitted per unit of fuel consumed, etc. In this specific situation the emission factor is expressed by the grams of pollutant emission per kilometer.

The site of Ispra provides the emission factors of the year 2019 for each pollutant expressed in grams over kilometer as the Table 34 shows (ISPRA, 2019).

EMISSION FACTORS (g/km U)							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	0.012402	0.58644	0.00079	0.42849	0.030273	0.043801	242.925038
Public mobility	0.208329	0.228156	0.003341	6.931953	0.161088	0.21749	1097.78

Table 34 Emission factors (ISPRA, 2019)

The emission factors of the private mobility is higher than the emission factor of the public mobility only for the pollutant NMVOC, otherwise for the other pollutants the emission factor of the public mobility is higher than that of the private mobility.

2.1.4 VARIATION OF MOBILITY DURING COVID-19 IN ITALY

Italy was the first country in Europe to be infected by Covid-19. The highest risk occurred in some northern regions compared to central and southern Italy. Although the COVID-19 epidemic started almost simultaneously in both the north (Lombardia and Veneto) and in Lazio (central Italy) when the first cases were officially certified in early 2020, the disease spread more rapidly and with more serious consequences in regions with a higher epidemic risk. Using various methodologies, the evolution of travel during the pandemic period has been monitored, with particular attention to the reasons for traveling and using private and public transport.

The "Audimob" Observatory of Isfort carries out continuous sample surveys on the mobility of Italians (age group 14-80 years), through telephone and computer interviews. It is therefore possible, even within the limits of a partial survey, to estimate the trend of daily mobility behavior of citizens in the first phase of application of the restrictions due to the health emergency from Covid-19 (Prime Ministerial Decree of 11 March). To this end the relative data were processed as a sample to the period 12 March-3 May and were compared with the trends of 2019. The data refer to the interviewee's behavior on the day before the interview (ISFORT, 2020).

The data from the "Audimob" Observatory on the mobility behavior of Italians, which gives always structure the central axis of the Report ("the analysis of the demand"), have been then processed until 15 October 2020 and used to sketch out a scenario forecast on the future of the mobility of Italians, at least on the two main sides of the volumes of demand and modal repositioning.

The research of the mobility of Italian people during Covid-19 provides the average length of daily trips and the number of daily passengers per kilometer in Italy. During the lockdown period (12 March - 3 May) there was a predictable vertical drop in demand volumes compared to pre-Covid19 ordinary regime (reference to the 2019 average) estimated at over 65% less than daily travel of more than 80% fewer passengers*km. On the drastic reduction of the distances has affected, besides the strong decrease of the distances daily per capita, also reducing the average travel length (about the 40%) (ISFORT, 2020) (ISFORT, 2020).

Table 35 shows the average length of daily trips in Italy (expressed in kilometer) for each period considered.

Average length of daily trips (km) in Italy		
Average 2019	from 12/03/2020 to 03/05/2020	from 18/05/2020 to 15/10/2020
11.5	5.8	10.2

Table 35 Average length of daily trips for each period analyzed (ISFORT, 2020)

Table 36 shows the number of daily passengers per km in Italy for each period analyzed.

Number of millions of daily passenger-km in Italy		
Average 2019	from 12/03/2020 to 03/05/2020	from 18/05/2020 to 15/10/2020
1198	197	890

Table 36 Millions of daily passengers per km for each period analyzed (ISFORT, 2020)

During the pandemic, travel control rules and their consequences changes in citizens' mobility patterns have inevitably led to tangible impact on the choice of means of transport that have repositioned with decision in favour of non-motorised means, penalizing in particular the means of public transport. As for the car, the data show a substantial holding of the modal quotas, both during confinement (61%, three points less than the 2019 average), both in months successive (60,6%). In absolute values the travels in car have collapsed almost 70% during the lockdown and are bounced in the stage of post-confinement, but the recovery is not still complete (estimated a 20% reduction compared to the 2019 average). On the other hand, as might have been expected, the parties to the collective and intermodal mobility, whose modal split has fallen to 4.1% in the average value of lockdown, practically one third of the market share reached in 2019 (12.2%), while the loss of passengers has approached 90%. The concomitance of multiple factors clearly favoured this shift in modal quotas: drastic reduction in systematic travel (work and school commuting) which are proportionately more effectively met by collective mobility; the average shortening of trips that favors the most suitable modes for short distances (pedestrian mobility in the first place) and reduces the use of intermodal solutions; the rules of distance that discouraged "crowded" public transport; the widespread fear of contagion that also pushes citizens to avoid carriers "in sharing" (as it is a bus or train) and to use the car more in medium and long distances. After the reopening there has been a vigorous recovery of the share of collective mobility and exchange, which in the first post-confinement phase rose to 8% and then maintained this level also in the following months. Obviously, it is not a recovery complete, far from it: the modal share is still about a third lower than the 12.2% and especially in terms of daily passengers the volume reached is barely above half of that of 2019 (-46% estimated reduction of passengers among the first five months post-restriction and average 2019) (ISFORT, 2020).

Table 37 shows the percentage of daily trips for transport mode in Italy for the three different period considered.

Percentage of daily trips for transport mode in Italy					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
64	12.2	61	4.1	60.6	7.9

Table 37 Percentage of daily trips for transport mode for each period considered (ISFORT, 2020)

2.2 CALCULATIONS

In the chapter 2.1 DATA AND METHODS it was described the procedure to find the total extent of roads and the population of each area of Italy. In this chapter the calculations referred to them have been developed. By dividing the total roads in km (extent) for the population it is possible to obtain a proxy value (km/population) and by dividing the population for the total roads in km (extent) it is possible to obtain the other proxy value (population/km). The proxy value of the total region corresponds to the sum of each proxy value of each province.

$$Proxy = \frac{E}{P}$$

(1)

$$Proxy = \frac{P}{E}$$

(2)

where:

- E: total roads expressed in km including highways, national roads, regional roads, provincial roads and roads to be classified;
- P: population.

Then for each proxy value it is possible to obtain the percentage of each province with respect to the region:

$$Pc = \frac{proxy}{total\ proxy} \times 100$$

(3)

where:

- proxy: value of total roads over the population and the population over the total roads;
- total proxy: sum of each proxy value of the province;
- Pc: percentage of each province with respect to the region.

Taking into consideration the values of passenger per kilometer from (EUROSTAT, 2019), the previous proxy value calculated (population/km) and the relative percentage, by using these percentages, it is possible to calculate the passengers for each kilometer for each area and for each region in the year 2019. This has been developed both for private mobility and public mobility. Then, each value has been divided for 12 (number of total months in one year) in order to obtain the values of millions of passengers per kilometer for one month. The following formula explain better the procedure that have been done.

$$\frac{Pass}{D} = Mpr \times Pc$$

(4)

$$\frac{Pass}{D} = Mpu \times Pc$$

(5)

where:

- Pass: passenger;
- D: distance in kilometer;
- Mpr: private mobility;
- Mpu: public mobility;
- Pc: percentage calculated by population/km proxy.

2.2.2 EXTERNAL COSTS OF ROAD TRANSPORT

By using the costs expressed in cent per passenger per kilometer and by knowing the monthly passenger per kilometer (from previous calculations) it is possible to calculate the monthly average external costs for each mobility and for each category.

Now the procedure referred to the costs of Italy will be developed. It is possible to find the number of vehicles per kilometer by making an assumption of an average of 2.5 passengers of the private mobility and 30 passengers of the public mobility, as follows.

$$\frac{Veh}{D} = \frac{\frac{Pass}{D}}{n° \, of \, Pass}$$

(6)

Where:

- Veh: vehicles;
- D: distance (in km);
- Pass: passenger.

Table 38 shows the number of passengers assumed for each transport mode.

Transport mode	n° of passengers
Private mobility	2.5
Public mobility	30

Table 38 Passenger number assumption for each transport mode

Once that the emission factors are available (2.1.3 EMISSION ANALYSIS) and so the values in grams/kilometer and having the vehicles per kilometer it is possible to obtain the grams per the kilometer for each pollutant for each area of Italy and for each mobility. By having the grams, it is possible to convert in kilograms and so obtain the values expressed in kilograms per kilometer.

$$\frac{W}{D} = \frac{Veh}{D} \times \frac{E.F.}{1000}$$

(7)

where:

- W: weight (kg);
- D: distance (km);
- Veh: vehicles;
- E.F.: indicates emission factor available from Ispra site (ISPRA, 2019);
- 1000: conversion factor (to be divided in order to convert from grams to kilograms).

By having the values of kilograms of air pollution per kilometer and the previous values of average costs in euro over kilogram it's possible to find the values expressed in euro per kilometer:

$$\frac{C}{D} = \frac{W}{D} \times \frac{C}{W}$$

(8)

Where:

- C: cost (euro);
- D: distance (km);
- W: weight (kg).

2.2.3 VARIATION OF MOBILITY DURING COVID-19 IN ITALY

In order to calculate the number of daily passengers per kilometer for each transport mode for each period it is important to apply the percentage of each transport mode to daily passenger per kilometer. The calculation is referred to data reported in the section 2.1.4 VARIATION OF MOBILITY DURING COVID-19. Taking into consideration the emission factors in grams per kilometer (described in the section 2.1.3 EMISSION ANALYSIS) and the average length of daily trips in kilometer, it is possible to obtain the total grams that express the daily emission of each pollutant for each transport mode and for each period.

$$E = EF * L$$

(9)

Where:

- E: daily emission of each pollutant (g)
- EF: emission factor (g/km)
- L: average length of daily trips (km).

Once obtained the grams of the emission, with a simple conversion, it is possible to obtain the kilograms of daily emission. By knowing the average external costs (euro/kg) it is possible to obtain the total euro of daily emission for each pollutant as will be analyzed in the section of the results.

Furthermore, by knowing the number of daily passengers per km and multiplying per the average external costs provided by the Handbook, it is possible to obtain the daily average external costs expressed in euro.

$$DC = c * \frac{pass}{km} / 100$$

(10)

Where:

- DC: daily costs (euro);
- c: average costs (euro-cent per pkm)
- 100: conversion from cent to euro.

It is also possible, in conclusion, to apply the percentage to the total of the two transport modes in order to understand how much is the contribution of private and public mobility.

3. RESULTS

In this section the results of the previous data and calculations will be analyzed. The results are obtained on the basis of the scientific researches provided in the section 2.1 DATA AND METHODS and on the basis of the calculations developed in the section 2.2 CALCULATIONS.

In the first part the proxy values referred to kilometer/population and population/km have been analyzed. Tables from Table 39 to Table 58 show the proxy values that have been calculated (km per population and population per kilometer) and their relative percentages.

PIEMONTE											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Alessandria	181			2129		2310	411922	0.0056	14.75	178.32	8.26
Asti	45	12		1312	7	1376	209648	0.0066	17.27	152.36	7.06
Biella				708	6	715	171838	0.0042	10.95	240.33	11.14
Cuneo	119	245		3300	19	3683	582353	0.0063	16.64	158.12	7.33
Novara	103	59		778	16	957	362199	0.0026	6.95	378.47	17.54
Torino	301	157		2766		3224	2212996	0.0015	3.83	686.41	31.81
Verbania	18	186		538		741	155065	0.0048	12.57	209.26	9.70
Vercelli	101			981		1083	167189	0.0065	17.04	154.38	7.15
Total Piemonte	867	659		12512	49	14088	4273210	0.0380	100.00	2157.66	100.00

Table 39 Proxy values (km/population and population/km) of each province Piemonte region

For Piemonte region the highest percentage of the proxy (population/km) is occupied by the province of Torino.

VALLE D'AOSTA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Aosta	109	153	500			762	123895	0.0062	100	162.59	100
Total Valle D'Aosta	109	153	500			762	123895	0.0062	100	162.59	100

Table 40 Proxy values (km/population and population/km) of each province of Valle D'Aosta region

For Valle D'Aosta region there is only the contribution of one province (Aosta) showing as proxy value of population/km the value 162.59.

LOMBARDIA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Bergamo	32	46		1036	280	1394	1099621	0.0013	5.72	788.82	2.86
Brescia	130	155		1352	215	1852	1247583	0.0015	6.69	673.64	2.45
Como	23	97		548		668	594671	0.0011	5.06	890.23	3.23
Cremona	18			631	246	895	351698	0.0025	11.47	392.96	1.43
Lecco		72		469		541	332593	0.0016	7.33	614.77	2.23
Lodi	39	52		449		541	225885	0.0024	10.80	417.53	1.52
Mantova	38	20		827	295	1180	403585	0.0029	13.18	342.02	1.24
Milano	165	100		688	116	1069	3249821	0.0003	1.48	3040.06	11.04
Monza e Brianza	24	22				46	867421	0.0001	0.24	18856.98	68.46
Pavia	95	7		1730	326	2158	534951	0.0040	18.19	247.89	0.90
Sondrio		238		367		606	179234	0.0034	15.24	295.77	1.07
Varese	46	174		605	68	894	879929	0.0010	4.58	984.26	3.57
Total Lombardia	609	986		8702	1545	11842	9966992	0.0222	100.00	27544.93	100.00

Table 41 Proxy values (km/population and population/km) of each province of Lombardia region

For Lombardia region the highest contribution is occupied by the province of Monza and Brianza with a percentage of 68.46%. It means that the province is composed by an high number of inhabitants and low kilometer of extent of roads. In fact, the proxy value of population/km is 18856.98 for the province of Monza and Brianza with respect to the total proxy value of population/km of Lombardia with 27544.93. It is possible to see that the other proxy value (km/population) for the same province is very low.

TRENTINO ALTO ADIGE											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Bolzano	116			1234	823	2173	533715	0.0041	47.36	245.61	52.64
Trento	70			1510	884	2465	544745	0.0045	52.64	220.99	47.36
Total Trentino Alto	186			2744	1707	4638	1078460	0.0086	100.00	466.60	100.00

Table 42 Proxy values (km/population and population/km) of each province of Trentino Alto Adige region

For the region of Trentino Alto Adige the two provinces account for more or less the same contribution of proxy value (Bolzano with a percentage of 52.64% and Trento with a percentage of 47.36%).

VENETO											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Belluno	16	217	205	709		1147	199599	0.0057	32.26	174.02	5.12
Padova	74	87	167	1093		1421	929520	0.0015	8.58	654.13	19.23
Rovigo	25	82	124	546		777	229652	0.0034	18.99	295.56	8.69
Treviso	100	80	152	1276		1608	878070	0.0018	10.28	546.06	16.05
Venezia	107	126	129	879		1242	842942	0.0015	8.27	678.70	19.95
Verona	137	137	199	1504		1978	922291	0.0021	12.04	466.27	13.71
Vicenza	72	47	64	1266		1449	850379	0.0017	9.57	586.87	17.25
Total Veneto	530	777	1041	7273		9621	4852453	0.0178	100.00	3401.62	100.00

Table 43 Proxy values (km/population and population/km) of each province of Veneto region

For Veneto region, the highest percentage of proxy values of population/km are represented by Venezia province and Padova province and the lowest percentage is occupied by the province of Belluno.

FRIULI VENEZIA GIULIA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Gorizia	38	17	87	128	7	276	136809	0.0020	19.88	495.68	23.94
Pordenone	32		229	650	32	943	309058	0.0031	30.07	327.74	15.83
Trieste	30	22	34	135	8	229	229470	0.0010	9.84	1002.05	48.39
Udine	151	106	605	1270	3	2135	523416	0.0041	40.20	245.16	11.84
Total Friuli Venezia	250	145	954	2183	50	3582	1198753	0.0101	100.00	2070.64	100.00

Table 44 Proxy values (km/population and population/km) of each province of Friuli Venezia Giulia region

Friuli Venezia Giulia region is composed by the highest percentage of the province of Trieste (with 48.39%) and the lowest percentage of the province of Udine (11.84%).

LIGURIA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Genova	147	138		1037		1322	816916	0.0016	11.86	617.94	44.85
Imperia	61	129		788	6	985	208585	0.0047	34.62	211.76	15.37
La Spezia	64	78		631		773	215538	0.0036	26.29	278.83	20.24
Savona	105	99		777	17	998	268766	0.0037	27.22	269.30	19.55
Total Liguria	378	445		3233	24	4079	1509805	0.0136	100.00	1377.84	100.00

Table 45 Proxy values (km/population and population/km) of each province of Liguria region

The highest percentage of the proxy value population/km in Liguria is represented by the province of Genova, accounting for 44.85% of the total region.

EMILIA ROMAGNA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Bologna	172	153		1134	16	1475	1019539	0.0014	5.87	691.21	18.46
Ferrara	77	97		933		1107	341967	0.0032	13.13	308.91	8.25
Forlì-Cesena	43	181		1075	15	1315	393556	0.0033	13.56	299.28	7.99
Modena	51	165		1004	41	1260	704672	0.0018	7.25	559.26	14.94
Parma	94	92		1335	31	1552	453604	0.0034	13.88	292.27	7.81
Piacenza	92	107		1102	7	1309	284075	0.0046	18.70	217.02	5.80
Ravenna	48	162		817		1028	386309	0.0027	10.80	375.79	10.04
Reggio Emilia	40	110		1125	18	1293	526349	0.0025	9.97	407.08	10.87
Rimini	30	56	48	433		566	335478	0.0017	6.85	592.72	15.83
Total Emilia Romag	648	1123	48	8958	127	10904	4445549	0.0246	100.00	3743.54	100.00

Table 46 Proxy values (km/population and population/km) of each province of Emilia Romagna region

For Emilia Romagna region, the highest percentage of the proxy value population/km is occupied by Bologna province (with 18.46%) followed by Rimini (with 15.83%) and Modena (14.94%).

TOSCANA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Arezzo	70	125	184	1062	1	1441	336870	0.0043	12.03	233.78	3.83
Firenze	129	98	322	1086	2	1637	986001	0.0017	4.67	602.32	9.88
Grosseto		156	122	1708		1986	218538	0.0091	25.55	110.04	1.81
Livorno	34	96	67	517		715	329590	0.0022	6.10	460.97	7.56
Lucca	67	69	110	515		761	380676	0.0020	5.62	500.23	8.21
Massa Carrara	57	99	15	643	11	825	189841	0.0043	12.22	230.11	3.77
Pisa	42	80	203	823		1147	416425	0.0028	7.74	363.06	5.96
Pistoia	29	62	87	393		571	290819	0.0020	5.52	509.32	8.35
Prato	10		4	73		87	256047	0.0003	0.96	2943.07	48.28
Siena	61	92	206	1477		1837	263526	0.0070	19.60	143.45	2.35
Total Toscana	497	878	1321	8298	14	11008	3668333	0.0356	100.00	6096.34	100.00

Table 47 Proxy values (km/population and population/km) of each province of Toscana region

The highest percentage of the proxy value of population/km in Toscana region is represent by Prato province with 48.28% meaning that in this province there is a very low number of kilometer of roads (87 km).

UMBRIA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Perugia	48	396	777	1958		3180	643311	0.0049	50.34	202.30	49.66
Terni	46	141	235	657	3	1081	221702	0.0049	49.66	205.09	50.34
Total Umbria	94	537	1012	2615	3	4261	865013	0.0098	100.00	407.39	100.00

Table 48 Proxy values (km/population and population/km) of each province of Umbria region

For Umbria region, the two provinces account for the same percentage.

MARCHE											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Ancona	56	139		974		1170	465023	0.0025	10.74	397.46	34.19
Ascoli Piceno	44	39		959		1041	204575	0.0051	21.71	196.52	16.90
Fermo	28	27		856		912	170248	0.0054	22.86	186.68	16.06
Macerata	19	106		1505		1629	307421	0.0053	22.61	188.72	16.23
Pesaro Urbino	43	146		1644		1833	354139	0.0052	22.09	193.20	16.62
Total Marche	190	457		5938		6585	1501406	0.0234	100.00	1162.57	100.00

Table 49 Proxy values (km/population and population/km) of each province of Marche region

For Marche region, the highest percentage of population/km is occupied by Ancona province because of the high number of population.

LAZIO											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Frosinone	84	4	484	1562	29	2162	473467	0.0046	19.42	218.99	9.18
Latina		149	264	938		1351	561139	0.0024	10.24	415.35	17.40
Rieti	29	119	299	1129		1576	151668	0.0104	44.19	96.24	4.03
Roma	332	160	393	1968	18	2870	4227588	0.0007	2.89	1473.03	61.73
Viterbo	29	122	168	1360		1679	306934	0.0055	23.26	182.81	7.66
Total Lazio	473	553	1608	6958	47	9639	5720796	0.0235	100.00	2386.42	100.00

Table 50 Proxy values (km/population and population/km) of each province of Lazio region

Lazio region shows the highest percentage of proxy population/km for the province of Roma, having a very high number of inhabitants. In particular the percentage is 61.73% and the population is 4227588.

ABRUZZO											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Chieti	89	215		1786	8	2097	376397	0.0056	23.90	179.49	22.88
L'Aquila	131	433	562	1259		2385	292356	0.0082	35.00	122.58	15.63
Pescara	58	104		791	1	955	314689	0.0030	13.02	329.52	42.01
Teramo	89	238		1627	21	1975	301814	0.0065	28.08	152.82	19.48
Total Abruzzo	366	991	562	5463	31	7413	1285256	0.0233	100.00	784.41	100.00

Table 51 Proxy values (km/population and population/km) of each province of Abruzzo region

The highest percentage of the value of population/km in Abruzzo region is represent by Pescara province because it shows the lowest number of kilometers of extent of roads with respect to the other provinces.

MOLISE											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Campobasso	36	351		1254	3	1643	214629	0.0077	36.56	130.63	63.44
Isernia		232			856	1088	81918	0.0133	63.44	75.29	36.56
Total Molise	36	583		1254	859	2731	296547	0.0209	100.00	205.92	100.00

Table 52 Proxy values (km/population and population/km) of each province of Molise region

For Molise region, the highest percentage of proxy value is represented by Campobasso province because of the high number of inhabitants.

CAMPANIA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Avellino	110	275		1330	191	1906	405963	0.0047	30.33	212.99	4.81
Benevento	11	190		1270	10	1482	269233	0.0055	35.55	181.67	4.10
Caserta	71	242		1502		1816	911606	0.0020	12.87	501.99	11.33
Napoli	119	128	64	542	90	944	3017658	0.0003	2.02	3196.67	72.17
Salerno	193	475	455	2079		3202	1075299	0.0030	19.23	335.82	7.58
Total Campania	504	1310	520	6724	291	9350	5679759	0.0155	100.00	4429.14	100.00

Table 53 Proxy values (km/population and population/km) of each province of Campania region

Campania region is mainly influenced by the contribution of Napoli province accounting with a percentage of population/km of 72.17% because of the high number of population and the low value of kilometer of extent of road (944) with respect to the other provinces.

PUGLIA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Bari	78	251		1565		1893	1222818	0.0015	8.55	645.97	27.33
Barletta-Andria-Tra	44	131		584		759	382685	0.0020	10.95	504.20	21.33
Brindisi		136		927		1063	382454	0.0028	15.35	359.79	15.22
Foggia	170	636	20	2741	2	3569	601419	0.0059	32.77	168.51	7.13
Lecce		236		2196		2432	777507	0.0031	17.27	319.70	13.53
Taranto	23	212		1191	108	1533	560048	0.0027	15.11	365.33	15.46
Total Puglia	314	1602	20	9204	110	11250	3926931	0.0181	100.00	2363.49	100.00

Table 54 Proxy values (km/population and population/km) of each province of Puglia region

In Puglia region the highest percentage of population/km is represented by Bari province, followed by Barletta province (27.33% and 21.33% respectively).

BASILICATA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Matera		352			1412	1764	193457	0.0091	73.96	109.67	26.04
Potenza	65	709			363	1137	354122	0.0032	26.04	311.45	73.96
Total Basilicata	65	1061			1775	2902	547579	0.0123	100.00	421.12	100.00

Table 55 Proxy values (km/population and population/km) of each province of Basilicata region

The province of Potenza accounts for 73.96% of population/km in the total Basilicata region because it is composed by a lower number of inhabitants than the number of the other province.

CALABRIA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Catanzaro	47	264		1280		1591	346514	0.0046	21.70	217.80	12.42
Cosenza	138	621			6	766	684786	0.0011	5.29	893.98	50.98
Crotone		119		826		945	166617	0.0057	26.80	176.31	10.06
Reggio Calabria	78	242		1351	7	1679	526586	0.0032	15.07	313.63	17.89
Vibo Valentia	36	106		724	144	1010	153225	0.0066	31.15	151.71	8.65
Total Calabria	300	1352		4182	157	5991	1877728	0.0212	100.00	1753.43	100.00

Table 56 Proxy values (km/population and population/km) of each province of Calabria region

The province of Cosenza represents the highest percentage of population/km proxy value in Calabria region with 50.98% and the lowest percentage of km/population proxy value (5.29%).

SICILIA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Agrigento		563		879	5	1447	419847	0.0034	9.71	290.15	10.32
Caltanissetta	14	366		1147		1527	252803	0.0060	17.02	165.56	5.89
Catania	95	489		1315	12	1911	1066765	0.0018	5.05	558.22	19.85
Enna	66	444	73	784	6	1373	158183	0.0087	24.46	115.21	4.10
Messina	197	482		1423		2102	609223	0.0035	9.72	289.83	10.31
Palermo	172	753	102	1598		2624	1214291	0.0022	6.09	462.76	16.45
Ragusa		141	89	638		868	314950	0.0028	7.77	362.85	12.90
Siracusa	58	247	122	1056	70	1554	386451	0.0040	11.33	248.68	8.84
Trapani	124	332		849	6	1311	418363	0.0031	8.83	319.12	11.35
Total Sicilia	725	3819	386	9687	100	14717	4840876	0.0355	100.00	2812.38	100.00

Table 57 Proxy values (km/population and population/km) of each province of Sicilia region

In Sicily the highest contribution of proxy value population/km is occupied by Catania province (with 19.85%) followed by Palermo province (with 16.45%).

SARDEGNA											
Province	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
Cagliari		562		929		1490	420117	0.0035	11.60	281.96	27.71
Nuoro		774		1017	192	1983	202951	0.0098	31.96	102.35	10.06
Oristano		303		900		1203	153226	0.0079	25.68	127.37	12.52
Sassari		1029		2101	35	3165	481052	0.0066	21.52	151.99	14.94
Sud Sardegna		323		640		963	340879	0.0028	9.24	353.98	34.78
Total Sardegna		2990		5586	227	8803	1598225	0.0306	100.00	1017.64	100.00

Table 58 Proxy values (km/population and population/km) of each province of Sardegna region

The same work has been done for the different areas of Italy: North-West Italy, North-East Italy, Central Italy, South Italy and Insular Italy. Each area consists:

- North-West Italy: Piemonte, Valle D'Aosta, Lombardia, Liguria;
- North-East Italy: Trentino, Veneto, Friuli, Emilia-Romagna;

- Central Italy: Toscana, Umbria, Marche, Lazio;
- South Italy: Abruzzo, Molise, Basilicata, Campania, Puglia, Calabria;
- Insular Italy: Sardegna, Sicilia.

Table 59 shows the proxy values (km/population and population/km) and their relative percentage for each area of Italy and for the total Italy.

ITALY											
Area	Highways (km)	National roads (km)	Regional roads (km)	Provincial roads (km)	Roads to be classified (km)	Total roads (km)	Population	km/population	Percentage (%)	Population/km	Percentage (%)
North-West Italy	1963	2244	500	24448	1617	30771	15873902	0.0019	14.19	515.87	27.02
North-East Italy	1614	2045	2043	21158	1884	28745	11575215	0.0025	18.17	402.69	21.09
Central Italy	1255	2425	3941	23809	64	31493	11755548	0.0027	19.60	373.27	19.55
South Italy	1586	6900	1102	26826	3223	39637	13613800	0.0029	21.31	343.46	17.99
Insular Italy	725	6809	386	15273	327	23520	6439101	0.0037	26.73	273.77	14.34
Total Italy	7143	20423	7971	111514	7115	154166	59257566	0.0137	100.00	1909.07	100.00

Table 59 Proxy values (km/population and population/km) of Italy and each area of Italy

Figure 7 shows the percentage of each area of Italy referred to the proxy value that is the ratio between the total extent and the population.

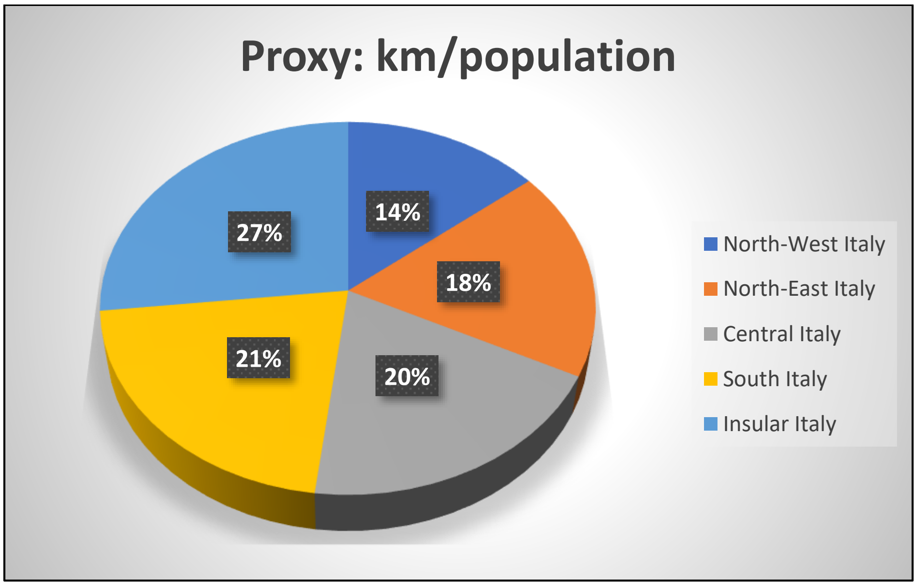

Figure 7 km/population percentage of each area of Italy

Insular Italy has the highest percentage, followed by South Italy, Central Italy, North-East Italy and North-West Italy.

Figure 8 shows the percentage of each area of Italy referring to the proxy value population over the total extent.

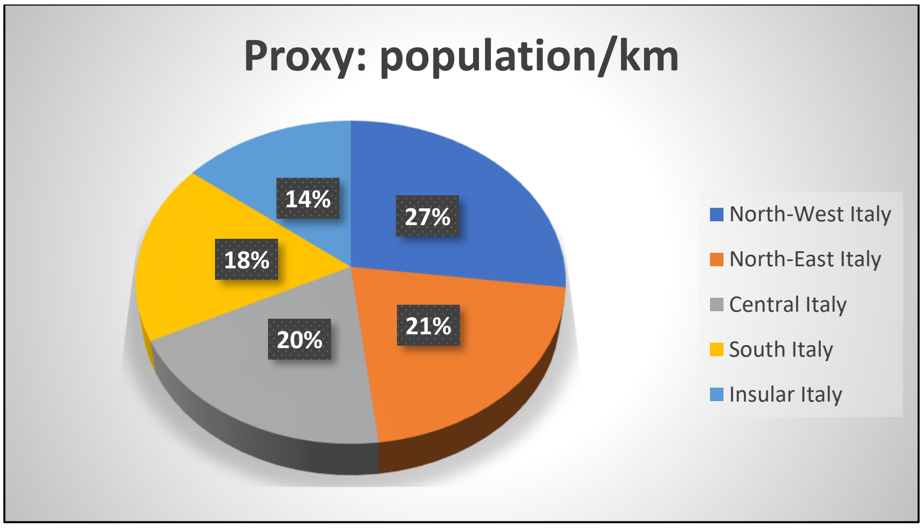

Figure 8 population/km percentage of each area of Italy

North-West Italy has the highest percentage followed by North-East Italy, Central Italy, South Italy and Insular Italy.

In order to develop the work related to passenger per kilometer it is important to take into consideration the proxy value population/kilometer.

Figures from Figure 9 to Figure 14 show the incidence of passenger per kilometer (referred to the population/kilometer) of each area in Italy and of each region in each area.

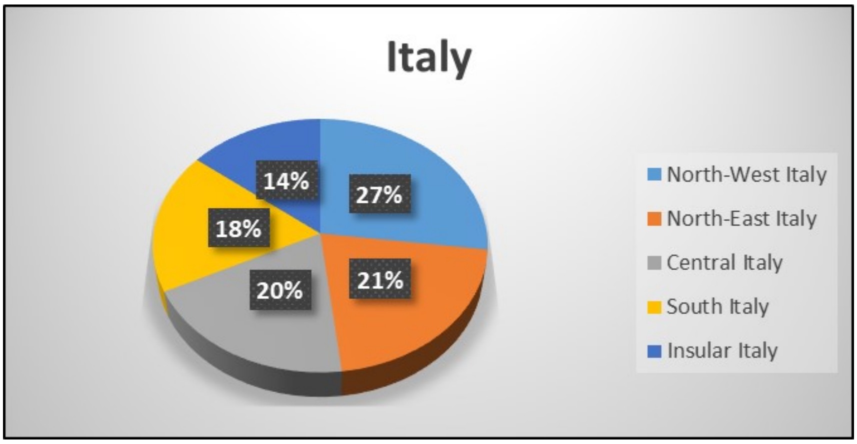

Figure 9 Incidence of passenger per kilometer of each area in Italy

With the same percentages of the proxy values (population/km) it is possible to determine the incidence of percentage of passenger per kilometer. In particular the North-West Italy accounts for 27%, North-East Italy accounts for 21%, Central Italy accounts for 20%, South Italy accounts for 18% and Insular Italy accounts for 14%.

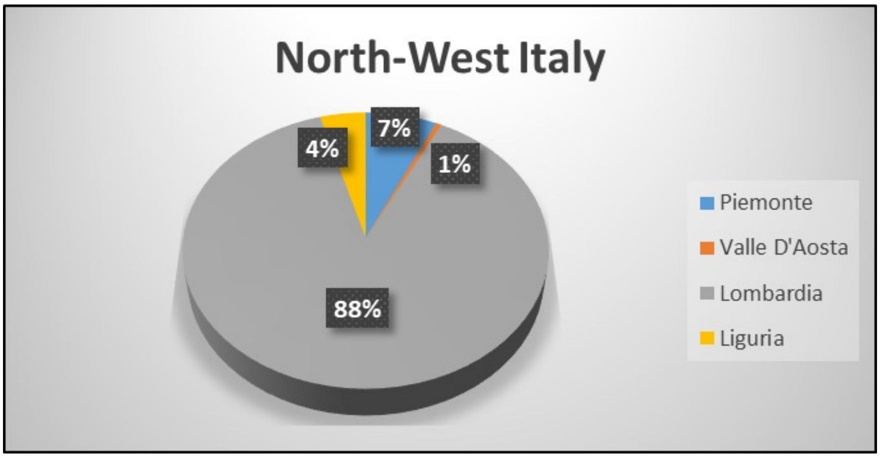

Figure 10 Incidence of passenger per kilometer for each region in N-W Italy

In the North-West Italy the highest percentage is occupied by Lombardia region (88%) because it is composed by some provinces that contain high number of inhabitants but low extent of kilometer of roads.

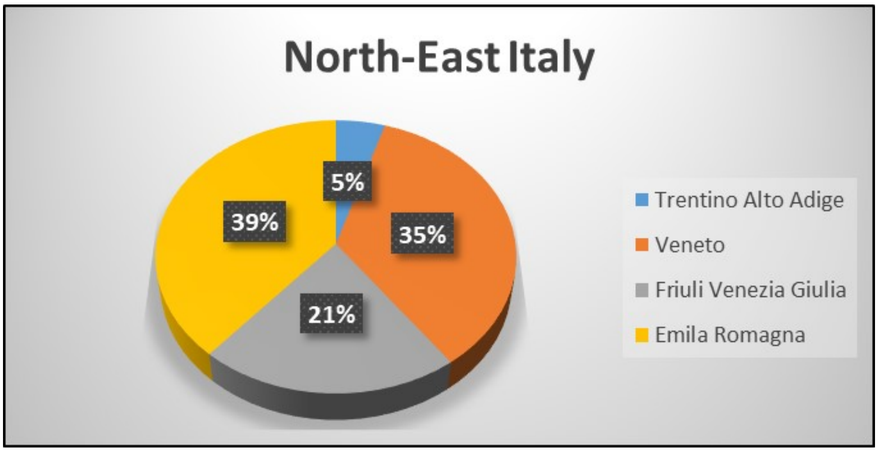

Figure 11 Incidence of passenger per kilometer for each region in N-E Italy

In the North-East Italy the highest contribution is represented by Emilia Romagna region followed by Veneto, Friuli Venezia Giulia and Trentino Alto Adige with 5%.

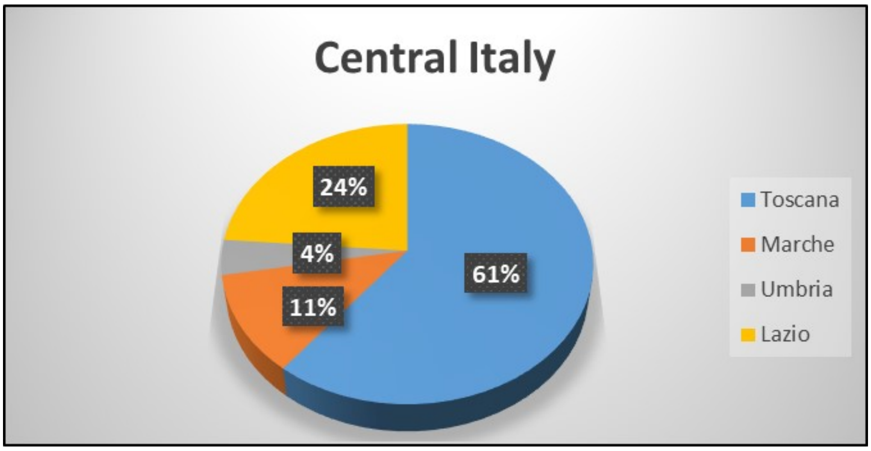

Figure 12 Incidence of passenger per kilometer for each region in Central Italy

In Central Italy the highest percentage is occupied by Toscana region (61%) because it is composed by some provinces that contain high number of inhabitants but low extent of kilometer of roads.

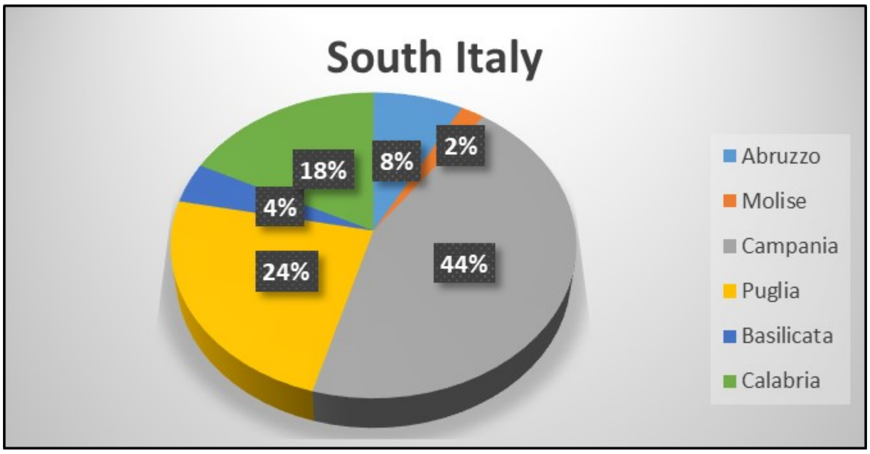

Figure 13 Incidence of passenger per kilometer for each region in South Italy

In South Italy the highest contribution is occupied by Campania region (44%), followed by Puglia, Calabria, Abruzzo, Basilicata and Molise.

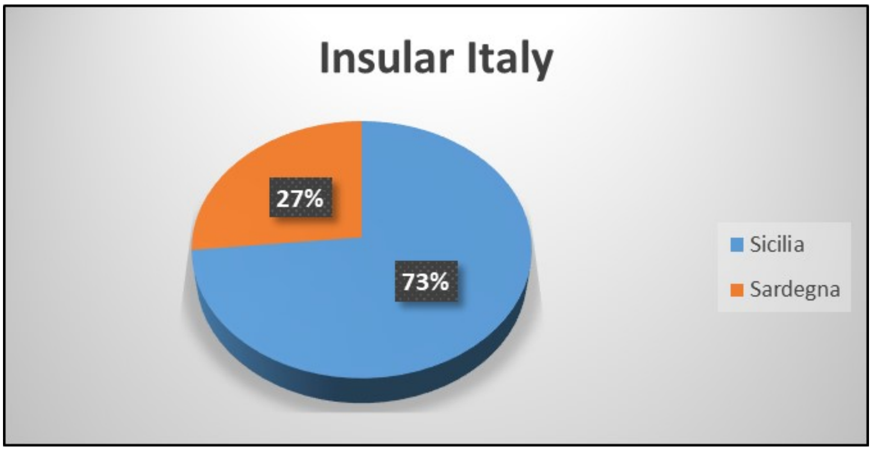

Figure 14 Incidence of passenger per kilometer for each region of Insular Italy

For Insular Italy, the highest percentage is represented by Sicilia with 73%.

By knowing the millions of passenger per kilometer of 2019 in Italy (from Eurostat) and by having the percentage referred to the proxy value population/km it is possible to apply the values of millions of passenger-km to these percentages in order to determine the millions of passenger-km in 2019 for private and public mobility. Once obtained these values, it is possible to determine the millions of passenger per kilometer as 2019 monthly average for each area of Italy and for private and public mobility.

Table 60 shows the millions of passengers per kilometer referred to the year 2019 for each transport mode for each area of Italy.

ITALY						
Areas	Population/km	Percentage (%)	Millions of passenger-km private mobility 2019	Millions of passenger-km public mobility 2019	Millions of passenger-km private mobility monthly	Millions of passenger-km public mobility monthly
North-West Italy	515.87	27.02	208508.3	27815.1	17375.7	2317.9
North-East Italy	402.69	21.09	162760.1	21712.2	13563.3	1809.4
Central Italy	373.27	19.55	150872.5	20126.4	12572.7	1677.2
South Italy	343.46	17.99	138822.5	18519.0	11568.5	1543.2
Insular Italy	273.77	14.34	110654.5	14761.3	9221.2	1230.1
Italy	1909.07	100.00	771618.0	102934.0	64301.5	8577.8

Table 60 Millions of passenger-km (2019 average and 2019 monthly average) for each area of Italy

It is possible to see that highest value of millions of passengers per kilometer is represented by North-West Italy with 17375.7 million of passenger-km each month for the private mobility and 2317.9 million of passenger-km each month for the public mobility.

Table 61, Table 62, Table 63, Table 64, Table 65 show the millions of passengers per kilometer referred to the year 2019 for each transport mode for each region of each area of Italy.

NORTH-WEST ITALY						
Areas	Population/km	Percentage (%)	Millions of passenger-km private mobility 2019	Millions of passenger-km public mobility 2019	Millions of passenger-km private mobility monthly	Millions of passenger-km public mobility monthly
Piemonte	2157.66	6.91	14399.7	1920.9	1200.0	160.1
Valle D'Aosta	162.59	0.52	1085.1	144.8	90.4	12.1
Lombardia	27544.93	88.16	183828.2	24522.7	15319.0	2043.6
Liguria	1377.84	4.41	9195.4	1226.7	766.3	102.2
North-West Italy	31243.02	100.00	208508.3	27815.1	17375.7	2317.9

Table 61 Millions of passenger-km (2019 average and 2019 monthly average) for each region of N-W Italy

Lombardia region shows the highest contribution of North-West Italy with 15319 millions of passenger-km for the private mobility and 2043.6 millions of passenger-km for the public mobility each month.

NORTH-EAST ITALY						
Areas	Population/km	Percentage (%)	Millions of passenger-km private mobility 2019	Millions of passenger-km public mobility 2019	Millions of passenger-km private mobility monthly	Millions of passenger-km public mobility monthly
Trentino Alto Adige	466.60	4.82	7843.6	1046.3	653.6	87.2
Veneto	3401.62	35.13	57180.9	7627.9	4765.1	635.7
Friuli Venezia Giulia	2070.64	21.39	34807.2	4643.3	2900.6	386.9
Emila Romagna	3743.54	38.66	62928.5	8394.7	5244.0	699.6
North-East Italy	9682.40	100.00	162760.1	21712.2	13563.3	1809.4

Table 62 Millions of passenger-km (2019 average and 2019 monthly average) for each region of N-E Italy

Emilia Romagna region shows the highest contribution of North-East Italy with 5244 millions of passenger-km for the private mobility and 699.6 millions of passenger-km for the public mobility each month. It is followed by Veneto, Friuli Venezia Giulia and Trentino Alto Adige.

CENTRAL ITALY						
Areas	Population/km	Percentage (%)	Millions of passenger-km private mobility 2019	Millions of passenger-km public mobility 2019	Millions of passenger-km private mobility monthly	Millions of passenger-km public mobility monthly
Toscana	6096.34	60.64	91494.7	12205.4	7624.6	1017.1
Marche	1162.57	11.56	17448.0	2327.6	1454.0	194.0
Umbria	407.39	4.05	6114.1	815.6	509.5	68.0
Lazio	2386.42	23.74	35815.7	4777.8	2984.6	398.2
Central Italy	10052.71	100.00	150872.5	20126.4	12572.7	1677.2

Table 63 Millions of passenger-km (2019 average and 2019 monthly average) for each region of Central Italy

In Central Italy, Toscana represents the highest percentage of millions of passengers per kilometer showing 7624.6 for the private mobility and 1017.1 for the public mobility each month.

SOUTH ITALY						
Areas	Population/km	Percentage (%)	Millions of passenger-km private mobility 2019	Millions of passenger-km public mobility 2019	Millions of passenger-km private mobility monthly	Millions of passenger-km public mobility monthly
Abruzzo	784.41	7.88	10935.8	1458.8	911.3	121.6
Molise	205.92	2.07	2870.9	383.0	239.2	31.9
Campania	4429.14	44.48	61748.8	8237.3	5145.7	686.4
Puglia	2363.49	23.74	32950.6	4395.6	2745.9	366.3
Basilicata	421.12	4.23	5871.1	783.2	489.3	65.3
Calabria	1753.43	17.61	24445.4	3261.0	2037.1	271.8
South Italy	9957.51	100.00	138822.5	18519.0	11568.5	1543.2

Table 64 Millions of passenger-km (2019 average and 2019 monthly average) for each region of South Italy

South Italy is mainly influenced by Campania region, showing 5145.7 millions of passengers per kilometer for the private mobility and 686.4 millions of passengers per kilometer for the public mobility each month.

INSULAR ITALY						
Areas	Population/km	Percentage (%)	Millions of passenger-km private mobility 2019	Millions of passenger-km public mobility 2019	Millions of passenger-km private mobility monthly	Millions of passenger-km public mobility monthly
Sicilia	2812.38	73.43	81253.5	10839.2	6771.1	903.3
Sardegna	1017.64	26.57	29401.0	3922.1	2450.1	326.8
Insular Italy	3830.02	100.00	110654.5	14761.3	9221.2	1230.1

Table 65 Millions of passenger-km (2019 average and 2019 monthly average) for each region of Insular Italy

Sicilia is the region that mostly contributes to Insular Italy, showing 6771.1 millions of passengers per kilometer for the private mobility and 903.3 millions of passengers per kilometer for the public mobility each month.

Table 66 shows the monthly passenger per kilometer for each transport mode previous calculated.

Areas	Millions of passenger-km private mobility 1 month	Millions of passenger-km public mobility 1 month
N-W Italy	17375.7	2317.9
N-E Italy	13563.3	1809.4
Central Italy	12572.7	1677.2
South Italy	11568.5	1543.2
Insular Italy	9221.2	1230.1
Italy	64301.5	8577.8

Table 66 Monthly millions passenger-km for each transport mode for each area of Italy

It is possible to see that the highest contribution is represented by North-West Italy that accounts for 17375.7 millions of passenger per kilometer for the private mobility and 2317.9 millions of passenger per kilometer for the public mobility each month.

3.1 EXTERNAL COSTS OF ROAD TRANSPORT

In order to determine the costs of transport, the Handbook on external costs of 2019 has been analyzed. After the data provided in the chapter 2.1.2 EXTERNAL COSTS OF ROAD TRANSPORT and the calculations developed in the chapter 2.2.2 EXTERNAL COSTS OF ROAD TRANSPORT it is possible to obtain the results related to the external costs of road transport. Table 67 shows the average external costs calculated for each month for each category and for each transport mode. The costs are referred to the external costs of Europe provided by (Van Essen et al., 2019).

Areas	Monthly accident costs (euro/Km)		Monthly air pollution costs (euro/km)		Monthly climate change costs (euro/km)		Monthly noise costs (euro/km)		Monthly congestion costs (euro/km)		Monthly well to tank costs (euro/km)		Monthly abitate damage costs (euro/km)		Monthly total costs (euro/km)	
	private	public	private	public	private	public	private	public	private	public	private	public	private	public	private	public
N-W Italy	2988.6	46.4	243.3	34.8	364.9	20.9	1650.7	13.9	729.8	37.1	156.4	7.0	139.0	4.6	6272.6	166.9
N-E Italy	2332.9	36.2	189.9	27.1	284.8	16.3	1288.5	10.9	569.7	28.9	122.1	5.4	108.5	3.6	4896.4	130.3
Central Italy	2162.5	33.5	176.0	25.2	264.0	15.1	1194.4	10.1	528.1	26.8	113.2	5.0	100.6	3.4	4538.7	120.8
South Italy	1989.8	30.9	162.0	23.1	242.9	13.9	1099.0	9.3	485.9	24.7	104.1	4.6	92.5	3.1	4176.2	111.1
Insular Italy	1586.0	24.6	129.1	18.5	193.6	11.1	876.0	7.4	387.3	19.7	83.0	3.7	73.8	2.5	3328.9	88.6
Italy	2212.0	34.3	180.0	25.7	270.1	15.4	1221.7	10.3	540.1	27.4	115.7	5.1	102.9	3.4	4642.6	123.5

Table 67 Average external costs for each category, for each transport mode and for each area of Italy

Table 68 shows the vehicles per kilometer for each transport mode for each area of Italy, calculated with the passenger per kilometer and the assumption of 2.5 passenger for each vehicle of private mobility and 30 passengers for each vehicle of public mobility.

Areas	Vehicles/km private mobility 1 month	Vehicles/km public mobility 1 month
N-W Italy	6950.3	77.3
N-E Italy	5425.3	60.3
Central Italy	5029.1	55.9
South Italy	4627.4	51.4
Insular Italy	3688.5	41.0
Italy	25720.6	285.9

Table 68 Vehicles per kilometer in one month of each area of Italy

Once that the emission factors are available (2.1.3 EMISSION ANALYSIS) and so the values in grams/kilometer and having the vehicles per kilometer it is possible to obtain the grams per the kilometer for each pollutant for each area of Italy and for each mobility. By having the grams, it is possible to convert in kilograms and so obtain the values expressed in kilograms per kilometer.

Table 69 Air pollution cshows the pollutants of air pollution expressed in kilograms per kilometer.

AREAS	NH_3 (kg/km)		NMVOC (kg/km)		SO_2 (kg/km)		NO_X (kg/km)		$PM_{2.5}$ (kg/km)		PM_{10} (kg/km)	
	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month
N-W Italy	0.09	0.02	4.08	0.02	0.01	0.00	2.98	0.54	0.21	0.01	0.30	0.02
N-E Italy	0.07	0.01	3.18	0.01	0.00	0.00	2.32	0.42	0.16	0.01	0.24	0.01
Central Italy	0.06	0.01	2.95	0.01	0.00	0.00	2.15	0.39	0.15	0.01	0.22	0.01
South Italy	0.06	0.01	2.71	0.01	0.00	0.00	1.98	0.36	0.14	0.01	0.20	0.01
Insular Italy	0.05	0.01	2.16	0.01	0.00	0.00	1.58	0.28	0.11	0.01	0.16	0.01
Italy	0.32	0.06	15.08	0.07	0.02	0.00	11.02	1.98	0.78	0.05	1.13	0.06

Table 69 Air pollution compounds for each transport mode for each area of Italy

By having the values of kilograms of air pollution per kilometer and the previous values of average costs in euro over kilogram it’s possible to find the values expressed in euro per kilometer.

Table 70 shows the results of euro per kilometer for each pollutant and in particular the values of all Italy is expressed as an average of the values of each area.

AREAS	NH_3 (euro/km)		NMVOC (euro/km)		SO_2 (euro/km)		NO_X (euro/km)		$PM_{2.5}$ (euro/km)		PM_{10} (euro/km)	
	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month
N-W Italy	1.86	0.35	4.48	0.02	0.07	0.00	75.64	13.60	27.77	1.64	8.22	0.45
N-E Italy	1.45	0.27	3.50	0.02	0.05	0.00	59.05	10.62	21.68	1.28	6.42	0.35
Central Italy	1.35	0.25	3.24	0.01	0.05	0.00	54.73	9.84	20.10	1.19	5.95	0.33
South Italy	1.24	0.23	2.99	0.01	0.05	0.00	50.36	9.06	18.49	1.09	5.47	0.30
Insular Italy	0.99	0.18	2.38	0.01	0.04	0.00	40.14	7.22	14.74	0.87	4.36	0.24
Italy	1.38	0.26	3.32	0.01	0.05	0.00	55.99	10.07	20.56	1.22	6.08	0.34

Table 70 Euro/km of each pollutant of air pollution for each transport mode and for each area of Italy

The procedure illustrated was referred to air pollution costs. Now the costs referred to climate change are shown, with reference to CO_2 pollutant. Table 71 shows the values of kilograms per kilometer and the values of euro per kilometer of carbon dioxide pollutant, one of the most widespread in the climate change area.

AREAS	CO_2 (kg/km)		CO_2 (euro/km)	
	Private mobility 1 month	Public mobility 1 month	Private mobility 1 month	Public mobility 1 month
N-W Italy	1688.40	84.82	168.84	8.48
N-E Italy	1317.95	66.21	131.80	6.62
Central Italy	1221.69	61.37	122.17	6.14
South Italy	1124.12	56.47	112.41	5.65
Insular Italy	896.03	45.01	89.60	4.50
Italy	6248.18	313.89	124.96	6.28

Table 71 kg/km and euro/km for CO2 in climate change

Table 72 shows a comparison between the costs referred to Europe and the costs referred to Italy (obtained by the sum of each pollutant for air pollution costs and climate change costs), distinguishing by private mobility and public mobility.

	EUROPE				ITALY			
AREAS	Monthly air pollution cost (euro/km)		Monthly climate change cost (euro/km)		Monthly air pollution cost (euro/km)		Monthly climate change cost (euro/km)	
	private	public	private	public	private	public	private	public
N-W Italy	243.3	34.8	364.9	20.9	118.1	16.1	168.8	8.5
N-E Italy	189.9	27.1	284.8	16.3	92.2	12.5	131.8	6.6
Central Italy	176.0	25.2	264.0	15.1	85.4	11.6	122.2	6.1
South Italy	162.0	23.1	242.9	13.9	78.6	10.7	112.4	5.6
Insular Italy	129.1	18.5	193.6	11.1	62.7	8.5	89.6	4.5
Italy	180.0	25.7	270.1	15.4	87.4	11.9	125.0	6.3

Table 72 European and Italian costs for each transport mode for each area of Italy

Table 73 shows the values of air pollution costs and climate change costs (in euro per kilometer) for each area considering the total mobility (obtained by the sum of private and public mobility).

	EUROPE costs		ITALY costs	
AREAS	Monthly air pollution cost (euro/km)	Monthly climate change cost (euro/km)	Monthly air pollution cost (euro/km)	Monthly climate change cost (euro/km)
N-W Italy	278.0	385.8	134.1	177.3
N-E Italy	217.0	301.1	104.7	138.4
Central Italy	201.2	279.1	97.0	128.3
South Italy	185.1	256.8	89.3	118.1
Insular Italy	147.5	204.7	71.2	94.1
Italy	205.8	285.5	99.3	131.2

Table 73 European and Italian total costs (euro/km)

To better understand and see the comparison between the costs related to European point of view and Italy point of view, some graphs are reported, considering the air pollution for each area and the climate change for each area. Figure 15, Figure 16, Figure 17, Figure 18, Figure 19, Figure 20 show the comparison between the European costs and Italian costs referred to air pollution.

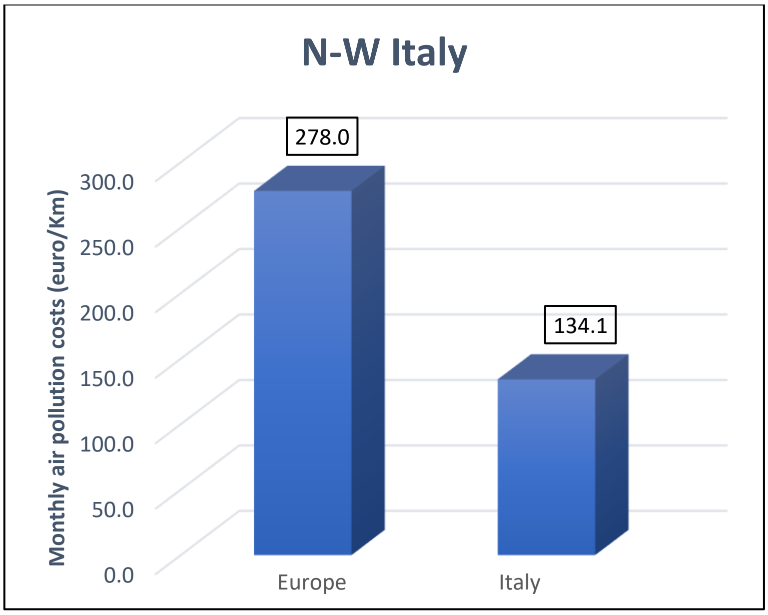

Figure 15 Comparison air pollution costs N-W Italy

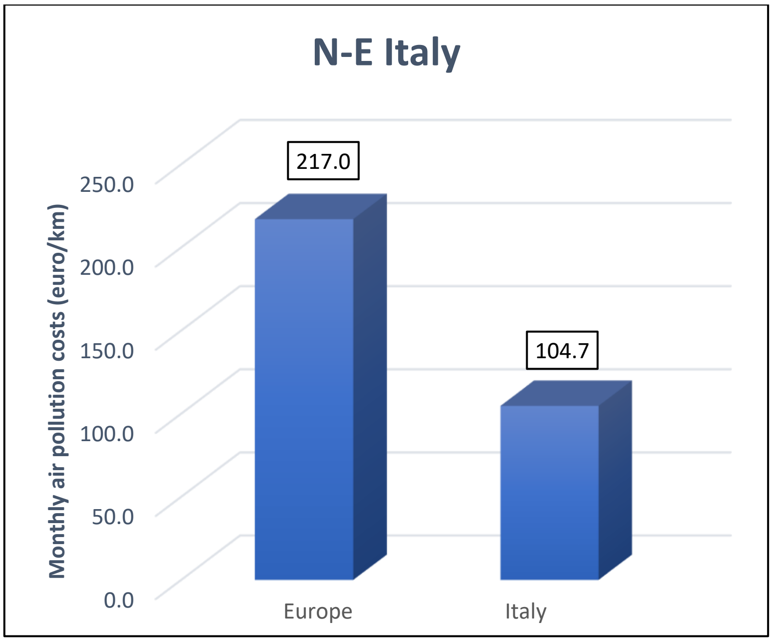

Figure 16 Comparison air pollution costs N-E Italy

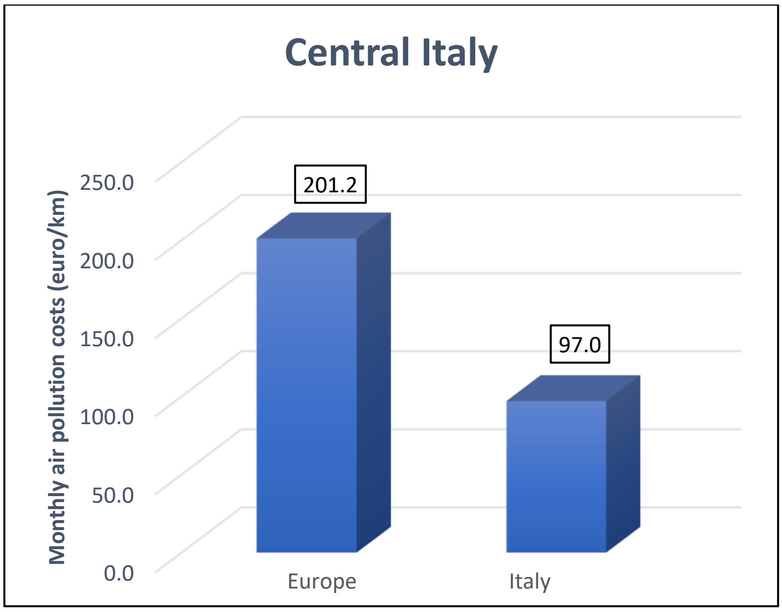

Figure 17 Comparison air pollution costs Central Italy

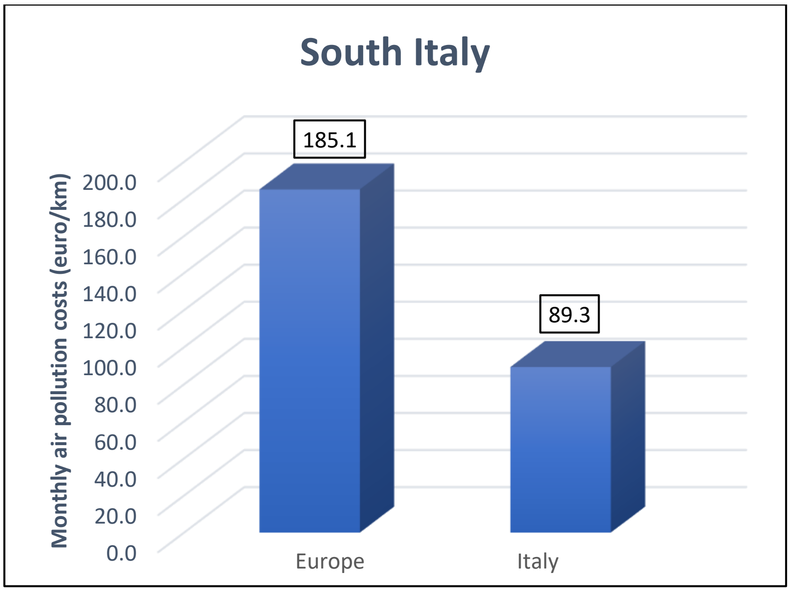

Figure 18 Comparison air pollution costs South Italy

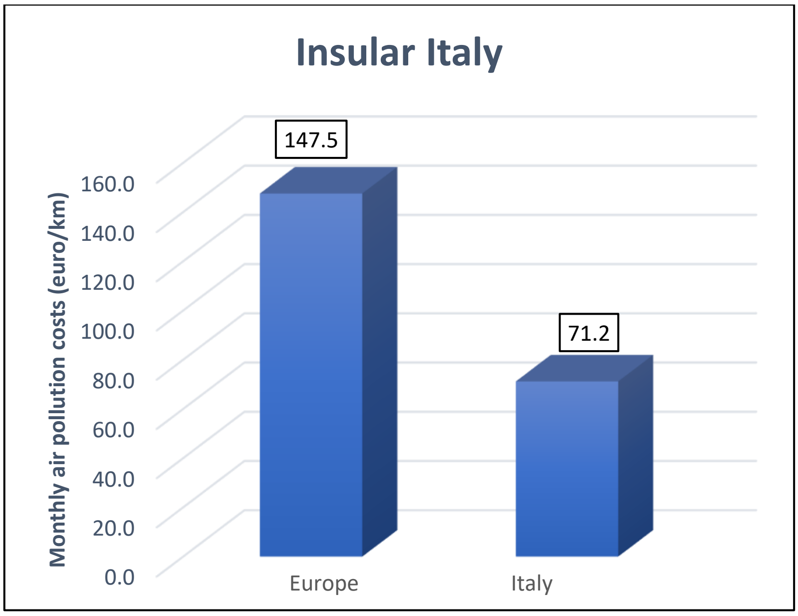

Figure 19 Comparison air pollution costs Insular Italy

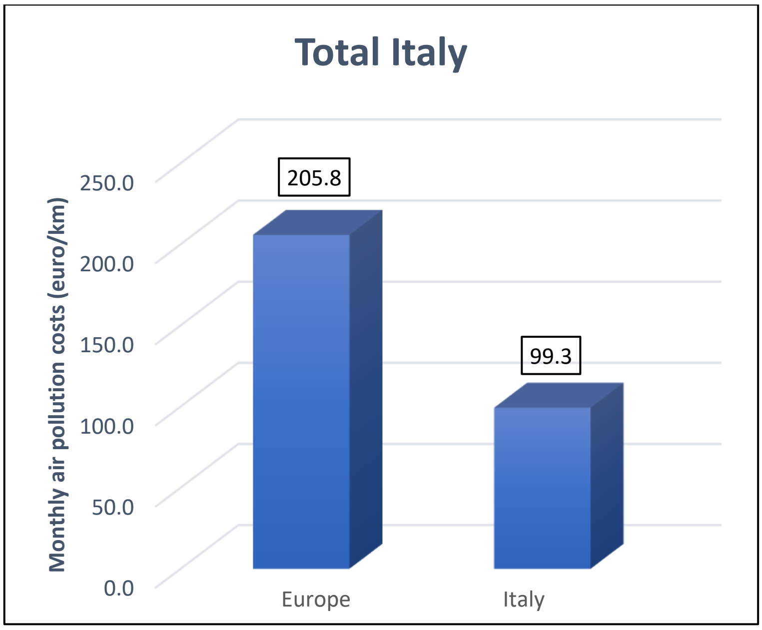

Figure 20 Comparison air pollution costs Italy

Figure 21, Figure 22, Figure 23, Figure 24, Figure 25, Figure 26 show the comparison between European climate change costs and Italian climate change costs.

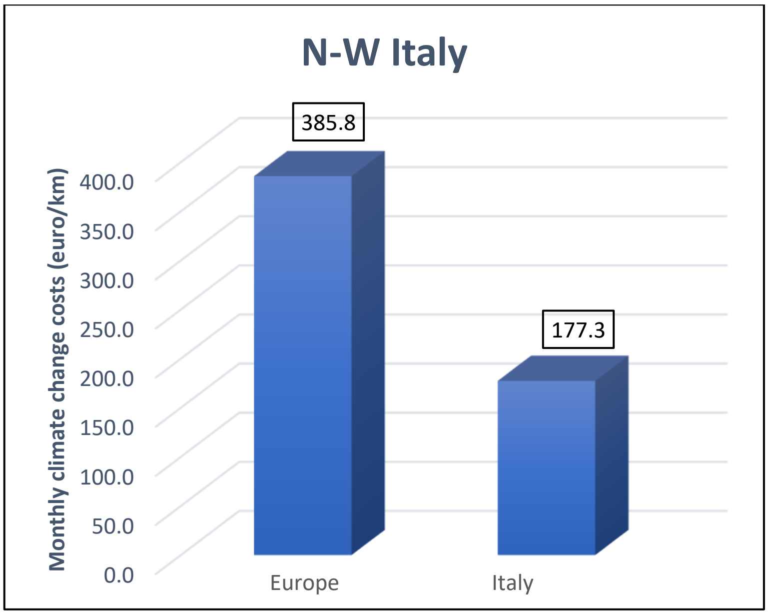

Figure 21 Comparison climate change costs N-W Italy

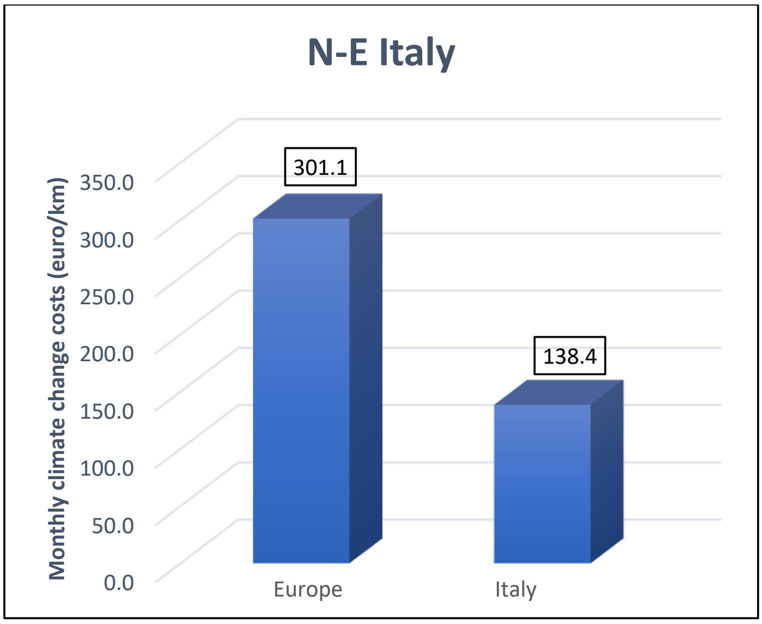

Figure 22 Comparison climate change costs N-E Italy

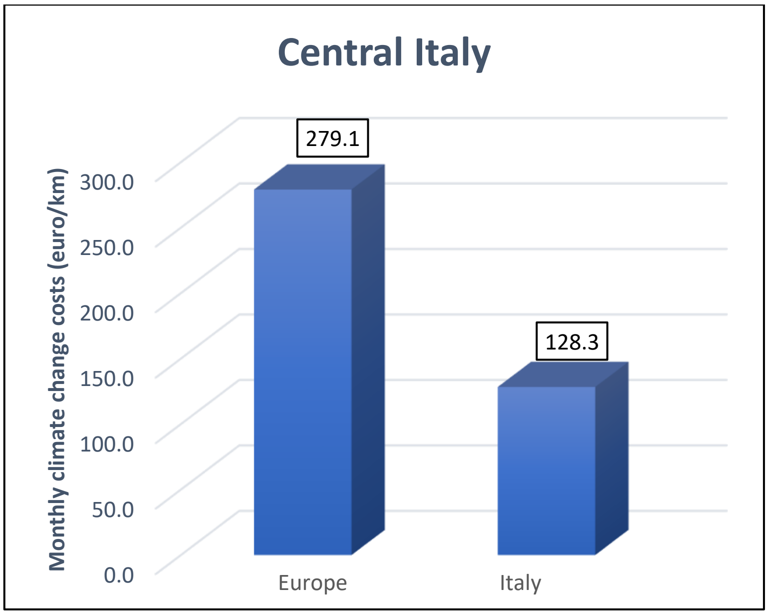

Figure 23 Comparison climate change costs Central Italy

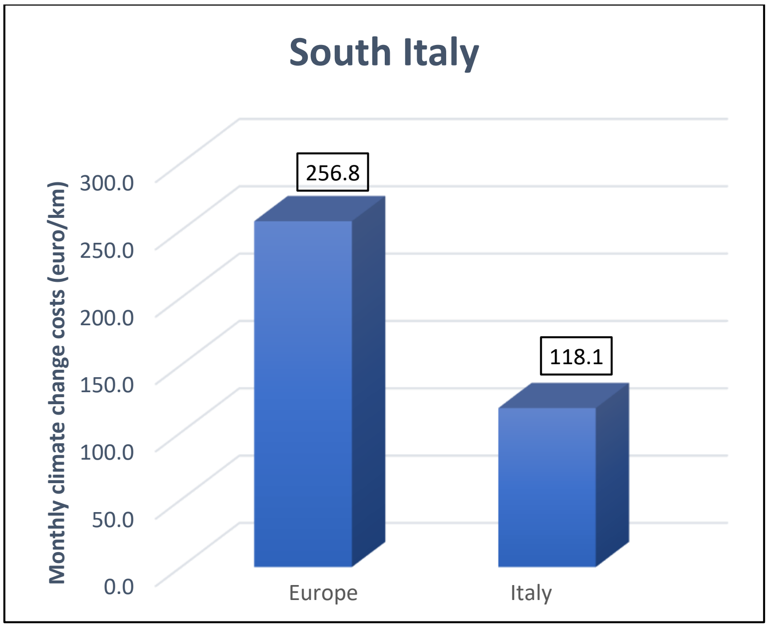

Figure 24 Comparison climate change costs South Italy

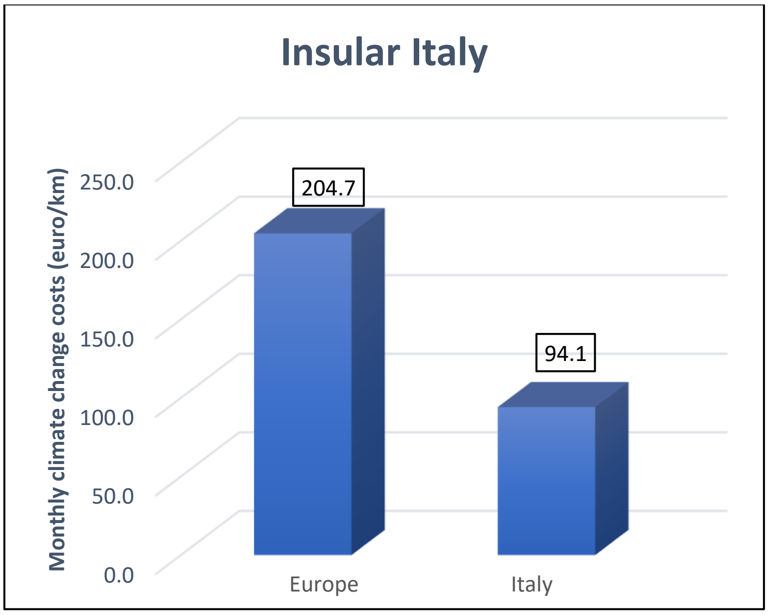

Figure 25 Comparison climate change costs Insular Italy

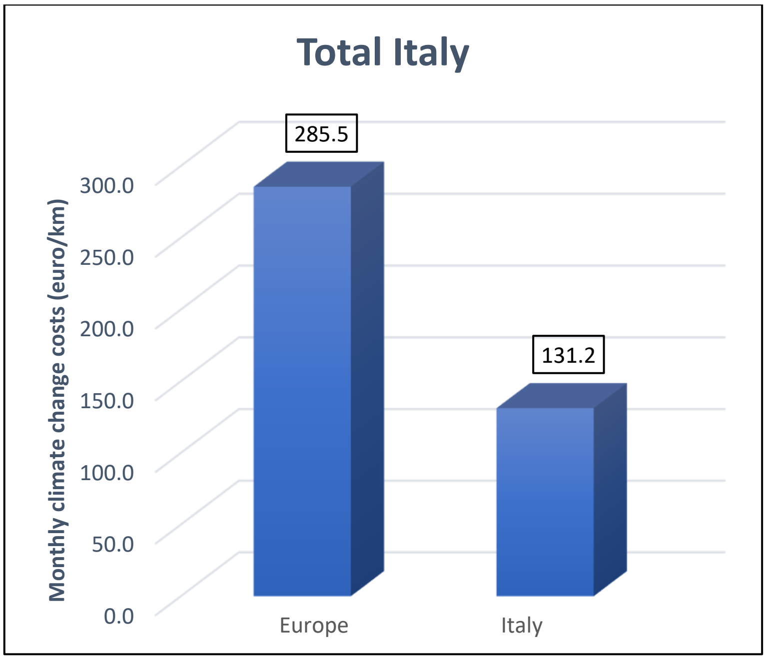

Figure 26 Comparison climate change costs Italy

3.2 VARIATION OF MOBILITY DURING COVID-19 IN ITALY

In most European countries, the pandemic led to a significant decrease in mobility, expressed as a lower number of trips per day and shorter distances per trip (Campisi, 2020). The number of daily passengers per kilometer and average length of daily trips in the section 2.1.4 VARIATION OF MOBILITY DURING COVID-19 are provided. In the same section the percentages referred to the type of transport mode (private and public mobility) are reported. By applying the percentage to the total values, it is possible to see the results of daily passenger per kilometer for each transport mode and the average daily length for each transport mode.

Table 74 shows the number of daily millions of passengers per kilometer for each transport mode for each period analyzed.

Number of daily millions of passenger-km for transport mode in Italy					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
766.72	146.156	120.17	8.077	539.34	70.31

Table 74 Daily millions of passenger-km for transport mode for each period considered

Table 74 shows as the daily millions of passengers per kilometer decrease during the lockdown. Considering the private mobility it possible to see that during the lockdown there was a decrease from 766.72 to 120.17 millions of passengers per kilometer with a subsequent increase after the lockdown reaching 539.34 millions of passengers per kilometer.

For the average length of daily trips, the same procedure has been done and Table 75 shows the results obtained by multiplying the percentage.

Average length of daily trips (km) for transport mode in Italy					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
7.36	1.403	3.538	0.2378	6.1812	0.8058

Table 75 Average length of daily trips for transport mode and for each period considered

Table 75 shows as the length of daily trips decreases during lockdown. In fact, it is possible to see that for the private mobility the average length goes from 7.36 km during 2019 to 3.538 km during lockdown, arising to 6.2 km after the lockdown. This means that during lockdown the average length of daily trips has halved.

Figure 27 and Figure 28 show the daily passenger per kilometer and the average daily length for each transport mode for each period considered to better understand the variation of the different periods. In particular with Lockdown 2020 is expressed the period from 12/03/2020 to 03/05/2020 and with post Lockdown 2020 is expressed the period from 18/05/2020 to 15/10/2020.

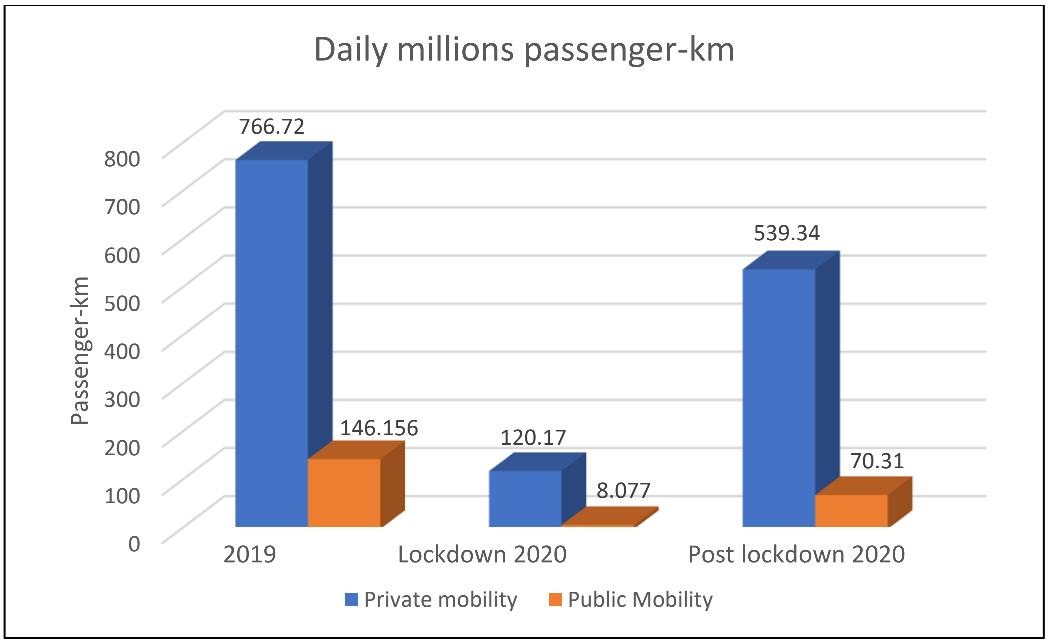

Figure 27 Daily millions of passenger-km for each transport mode and for each period considered

Figure 27 shows the decrease of passenger per kilometer during lockdown with values of 7 times lower than 2019 for the private mobility and 18 times lower for the public mobility.

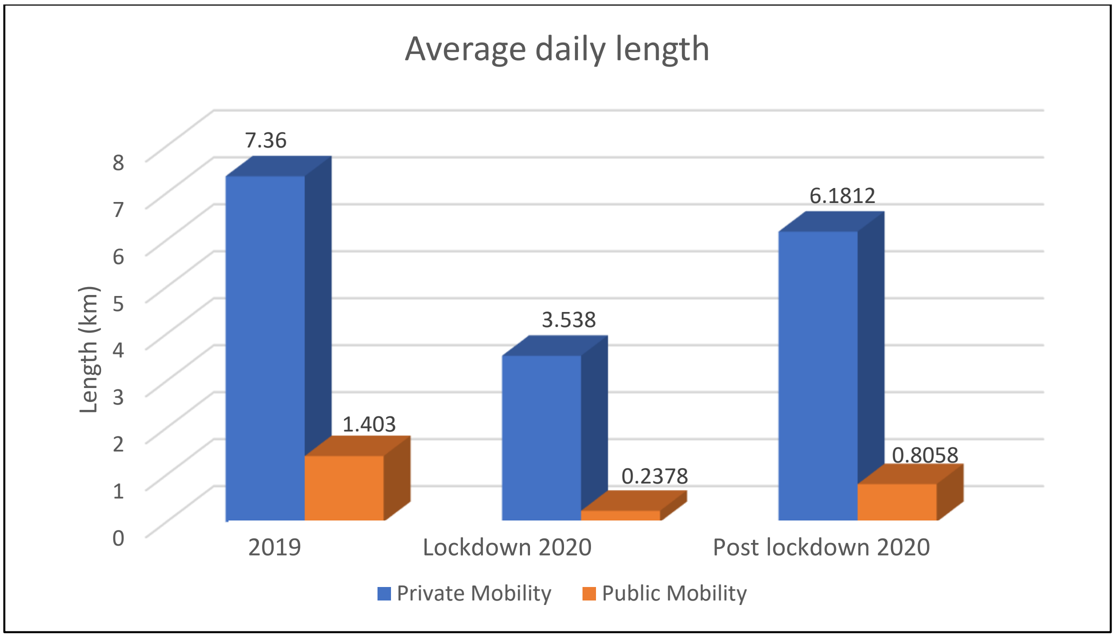

Figure 28 Average daily length for each transport mode and for each period considered

Figure 28 shows the decrease of the average daily length with values from 7.36 to 3.538 km for the private mobility and 1.403 to 0.24 km for the public mobility. The average daily length for the private mobility has helved and for the public mobility became 5 times lower.

Taking into consideration the emission factors in grams per kilometer and the average length of daily trips in kilometer, it is possible to obtain the total grams that express the daily emission of each pollutant for each transport mode and for each period.

Table 76, Table 77 and Table 78 show the daily emission of the pollutants for the three different period analyzed. It is visible how the daily emission during lockdown decreases: for example, taking into consideration the emission of NOx the values passed from 3.154 to 1.516 grams for the private mobility and from 9.726 to 1.648 grams for the public mobility.

Daily Emission (g) 2019 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	0.091	4.316	0.006	3.154	0.223	0.322	1787.928
Public mobility	0.292	0.320	0.005	9.726	0.226	0.305	1540.188

Table 76 Daily emission of pollutants for each transport mode (private and public mobility) during 2019

Daily Emission (g) from 12/03/2020 to 03/05/2020 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	0.044	2.075	0.003	1.516	0.107	0.155	859.469
Public mobility	0.050	0.054	0.001	1.648	0.038	0.052	261.052

Table 77 Daily emission of pollutants for each transport mode (private and public mobility) during lockdown 2020

Daily Emission (g) from 18/05/2020 to 15/10/2020 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	0.077	3.625	0.005	2.649	0.187	0.271	1501.568
Public mobility	0.168	0.184	0.003	5.586	0.130	0.175	884.592

Table 78 Daily emission of pollutants for each transport mode (private and public mobility) after lockdown 2020

Figures from Figure 29 to Figure 35 show the daily emission of each pollutant expressed in grams for each transport mode and for each period considered.

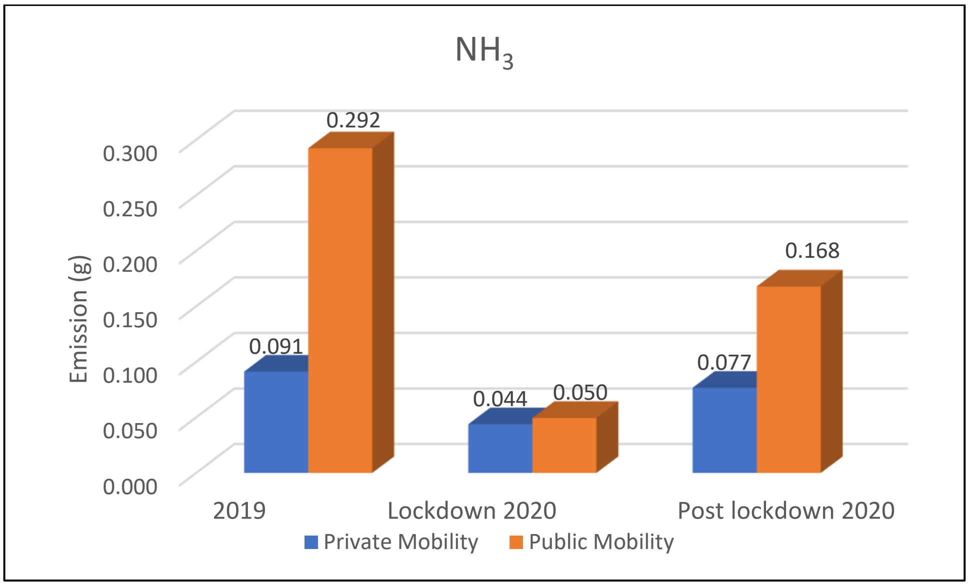

Figure 29 Daily NH_3 emission for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

The emission of ammonia shows values in 2019 of 0.091 grams for the private mobility and 0.292 grams for the public mobility since the emission factor for the public mobility is higher than that of the private mobility. During the lockdown the emission of ammonia for the private mobility has helved becoming 0.044 grams and for the public mobility it becomes almost 6 times lower with respect to the year 2019. After the lockdown the values started to increase showing 0.077 grams for the private mobility and 0.168 grams for the public mobility.

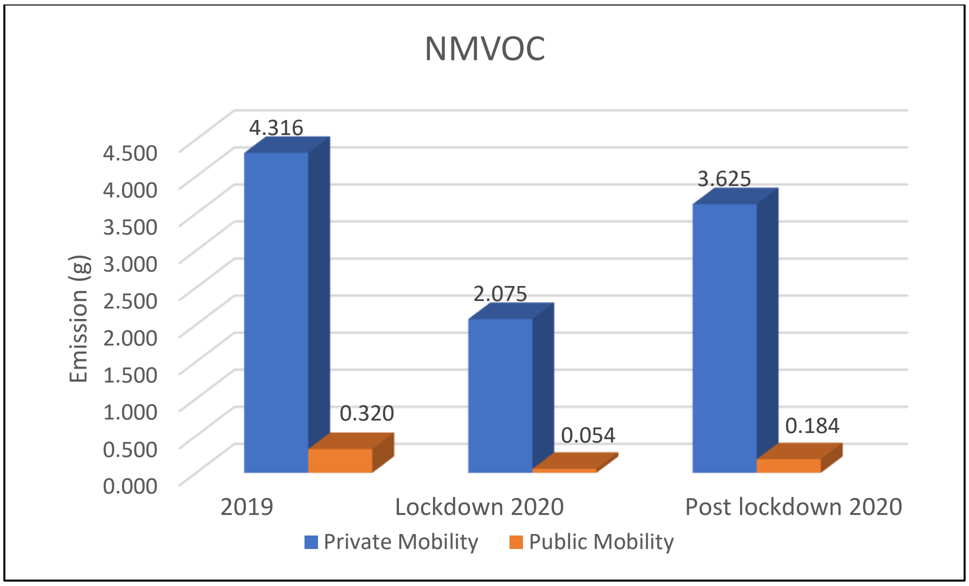

Figure 30 Daily NMVOC emission for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

The emission of non-methane volatile organic compounds shows values in 2019 of 4.316 grams for the private mobility and 0.320 grams for the public mobility. During the lockdown the emission of NMVOC for the private mobility helved becoming 2.075 grams and for the public mobility it becomes almost 6 times lower with respect to the year 2019, showing a value of 0.054 grams. After the lockdown the values started to increase showing 3.625 grams for the private mobility and 0.184 grams for the public mobility.

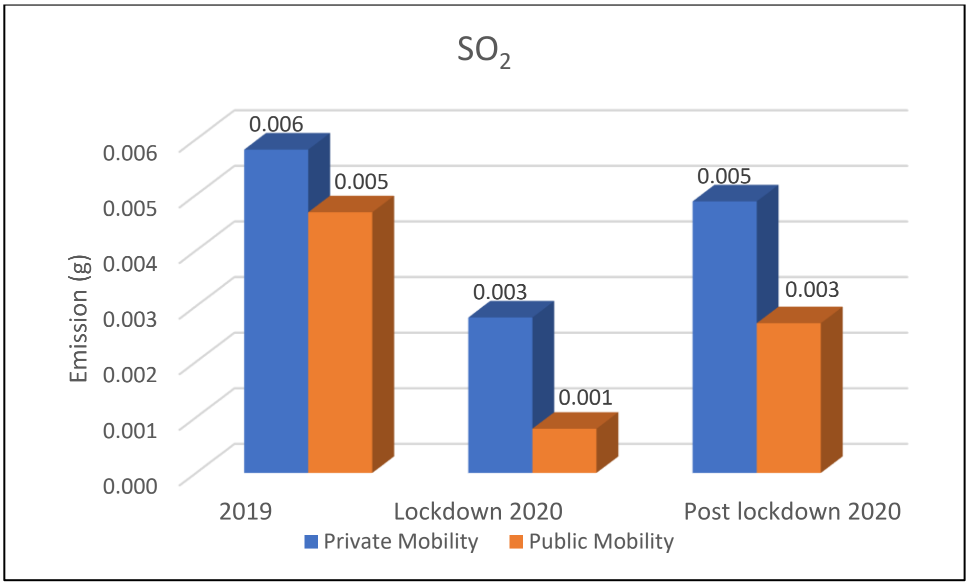

Figure 31 Daily SO_2 emission for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

The emission of sulfur dioxide shows values in 2019 of 0.006 grams for the private mobility and 0.005 grams for the public mobility. During the lockdown the emission of sulfur dioxide for the private mobility helved becoming 0.003 grams and for the public mobility it becomes almost 5 times lower with respect to the year 2019, showing a value of 0.001 grams. After the lockdown the values started to increase showing 0.005 grams for the private mobility and 0.003 grams for the public mobility.

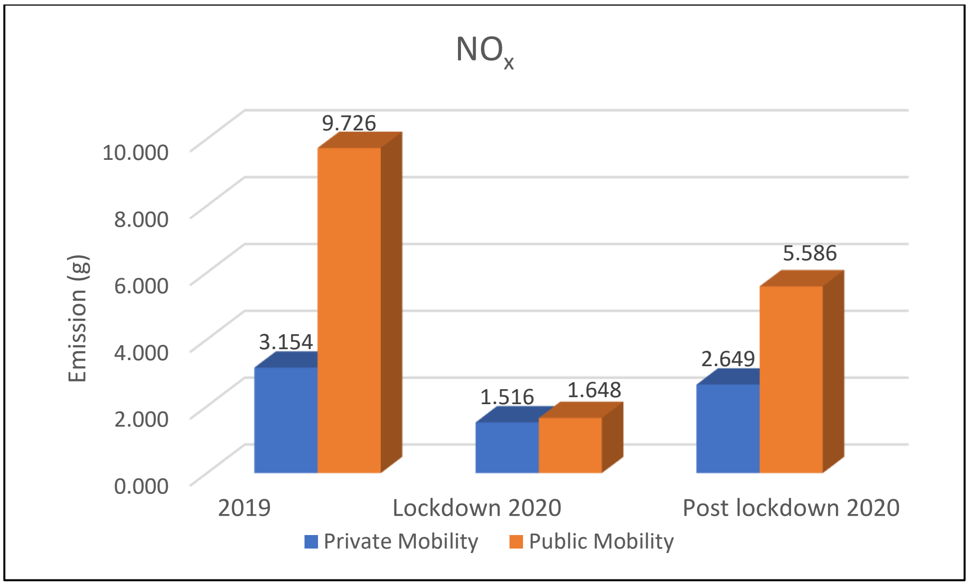

Figure 32 Daily NO_x emission for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

The emission of NO_x shows values in 2019 of 3.154 grams for the private mobility and 9.726 grams for the public mobility since the emission factor for the public mobility is higher than that of the private mobility. During the lockdown the emission of NO_x for the private mobility helved becoming 1.516 grams and for the public mobility it becomes almost 6 times lower with respect to the year 2019, showing a value of 1.648 grams. After the lockdown the values started to increase showing 2.649 grams for the private mobility and 5.586 grams for the public mobility.

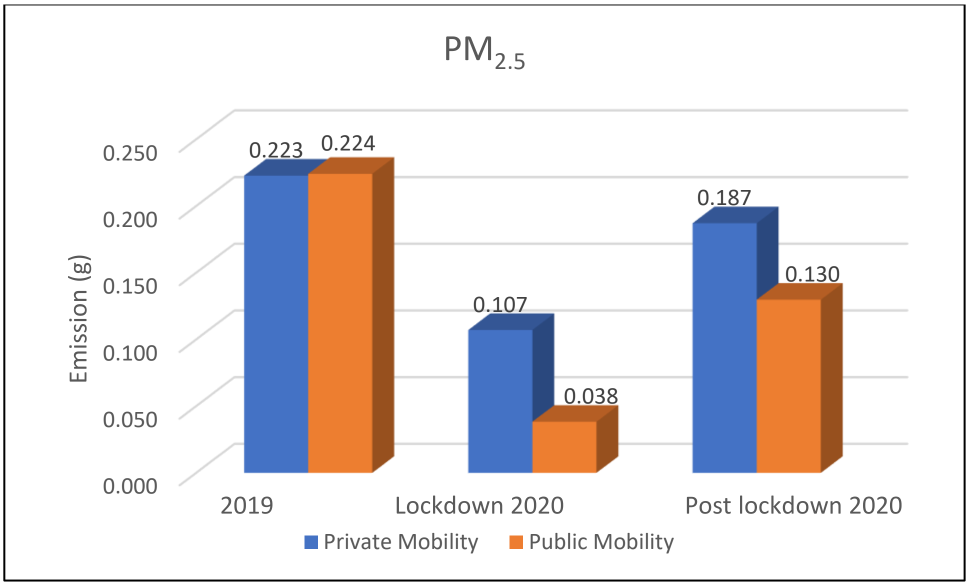

Figure 33 Daily $PM_{2.5}$ emission for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

The emission of $PM_{2.5}$ shows values in 2019 of 0.223 grams for the private mobility and 0.224 grams for the public mobility. During the lockdown the emission of $PM_{2.5}$ for the private mobility helved becoming 0.107 grams and for the public mobility it becomes almost 6 times lower with respect to the year 2019, showing a value of 0.038 grams. After the lockdown the values started to increase showing 0.187 grams for the private mobility and 0.130 grams for the public mobility.

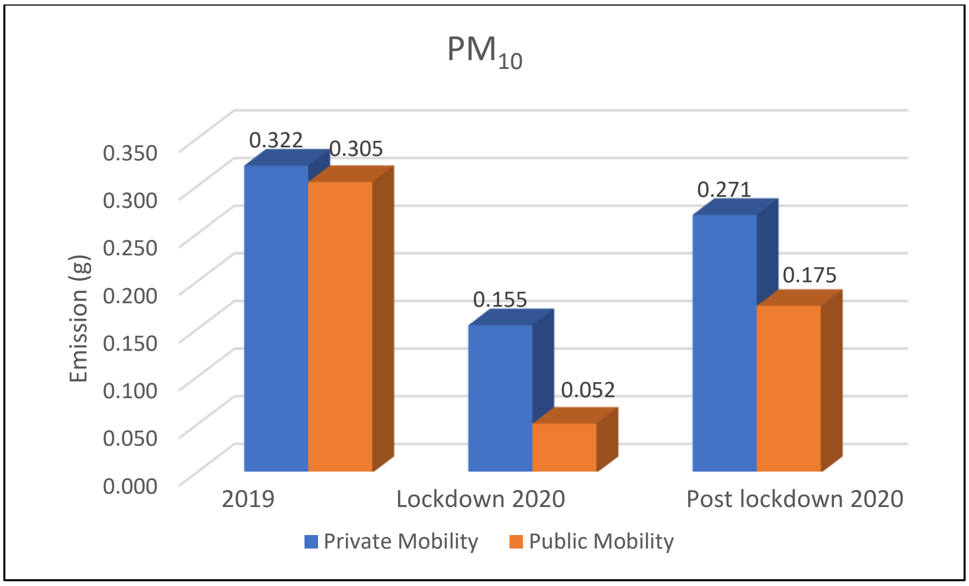

Figure 34 Daily PM_{10} emission for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

The emission of PM_{10} shows values in 2019 of 0.322 grams for the private mobility and 0.305 grams for the public mobility. During the lockdown the emission of PM_{10} for the private mobility helved becoming 0.155 grams and for the public mobility it becomes almost 6 times lower with respect to the year 2019, showing a value of 0.052 grams. After the lockdown the values started to increase showing 0.271 grams for the private mobility and 0.175 grams for the public mobility.

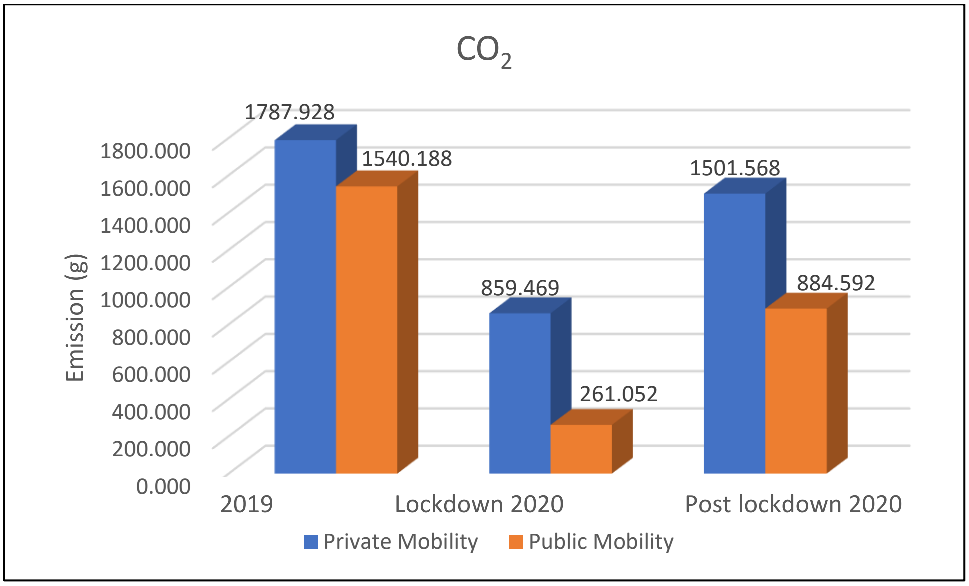

Figure 35 Daily CO_2 emission for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

The emission of CO_2 shows values in 2019 of 1788 grams for the private mobility and 1540 grams for the public mobility. During the lockdown the emission of CO_2 for the private mobility helved becoming 860 grams and for the public mobility it becomes almost 6 times lower with respect to the year 2019, showing a value of 261 grams. After the lockdown the values started to increase showing 1501 grams for the private mobility and 884 grams for the public mobility.

The figures from Figure 29 to Figure 35 show the different pollutants and their trend in the time. The time is referred to three different periods: before the lockdown in 2019, during lockdown in 2020 and after lockdown in 2020. All the pollutants demonstrate a significant decrease during the lockdown with respect to the period of 2019. After the lockdown the pollutants start to increase again but with values still lower than the values reported in 2019.

Once obtained the grams of daily emission of each pollutant it is possible to obtain the daily emission in kilograms by dividing per 1000, showed from Table 79 to Table 81.

Daily Emission (kg) 2019 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	9.13E-05	4.32E-03	5.81E-06	3.15E-03	2.23E-04	3.22E-04	1.79E+00
Public mobility	2.92E-04	3.20E-04	4.69E-06	9.73E-03	2.26E-04	3.05E-04	1.54E+00

Table 79 Daily emission of airborne pollutants from private and public mobility in 2019

Daily Emission (kg) from 12/03/2020 to 03/05/2020 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	4.39E-05	2.07E-03	2.80E-06	1.52E-03	1.07E-04	1.55E-04	8.59E-01
Public mobility	4.95E-05	5.43E-05	7.94E-07	1.65E-03	3.83E-05	5.17E-05	2.61E-01

Table 80 Daily emission of airborne pollutants from private and public mobility during lockdown

Daily Emission (kg) from 18/05/2020 to 15/10/2020 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	7.67E-05	3.62E-03	4.88E-06	2.65E-03	1.87E-04	2.71E-04	1.50E+00
Public mobility	1.68E-04	1.84E-04	2.69E-06	5.59E-03	1.30E-04	1.75E-04	8.85E-01

Table 81 Daily emission of airborne pollutants from private and public mobility during post lockdown

Once having the kilograms of daily emission and by knowing the average external costs from 2.1.2 EXTERNAL COSTS OF ROAD TRANSPORT, it is possible to obtain the cost (firstly in euro and then in cent) of each pollutant for each period for each transport mode. Tables from Table 82 to Table 84 show the daily costs expressed in euro.

Daily Costs (euro) 2019 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	0.002	0.005	0.000	0.080	0.029	0.009	0.179
Public mobility	0.006	0.000	0.000	0.247	0.030	0.008	0.154

Table 82 Daily external costs related to airborne pollutant emissions from private and public mobility in 2019

Daily Costs (euro) from 12/03/2020 to 03/05/2020 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	0.001	0.002	0.000	0.039	0.014	0.004	0.086
Public mobility	0.001	0.000	0.000	0.042	0.005	0.001	0.026

Table 83 Daily external costs related to airborne pollutant emissions from private and public mobility during lockdown

Table 83 shows how the costs of the pollutants decrease during the period of lockdown (from 12/03/2020 to 03/05/2020). For example, taking into consideration the pollutant $PM_{2.5}$ it is possible to say that daily costs referred to private mobility helved during lockdown with respect to the period of 2019. In fact, in 2019 the costs in euro for private mobility were 0.029 euros and 0.030 euros for the public mobility; during lockdown the costs were 0.014 euros for the private mobility and 0.005 euros for the public mobility.

Daily Costs (euro) from 18/05/2020 to 15/10/2020 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	0.002	0.004	0.000	0.067	0.025	0.007	0.150
Public mobility	0.004	0.000	0.000	0.142	0.017	0.005	0.088

Table 84 Daily external costs related to airborne pollutant emissions from private and public mobility during post lockdown

After the lockdown, the costs started to increase: by taking into consideration the same $PM_{2.5}$ it is visible that the daily costs are 0.025 euros for the private mobility and 0.017 for the public mobility.

Tables from Table 85 to Table 87 show the daily costs expressed in euro-cent, obtained by multiplying the values in euro per the conversion factor 100.

Daily Costs (euro-cent) 2019 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	0.20	0.47	0.01	8.01	2.94	0.87	17.88
Public mobility	0.63	0.04	0.01	24.70	2.98	0.82	15.40

Table 85 Daily external costs in euro-cent related to airborne pollutant emissions from private and public mobility in 2019

Daily Costs (euro-cent) from 12/03/2020 to 03/05/2020 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	0.09	0.23	0.00	3.85	1.41	0.42	8.59
Public mobility	0.11	0.01	0.00	4.19	0.51	0.14	2.61

Table 86 Daily external costs in euro-cent related to airborne pollutant emissions from private and public mobility during lockdown

The costs expressed in cent, for the pollutant CO_2 show that there is a decrease during lockdown passing from 17.88 cents to 8.59 cents for the private mobility and from 15.40 cents to 2.61 cents for the public mobility.

Daily Costs (euro-cent) from 18/05/2020 to 15/10/2020 in Italy							
Mobility	NH_3	NMVOC	SO_2	NO_X	$PM_{2.5}$	PM_{10}	CO_2
Private mobility	0.17	0.40	0.01	6.73	2.47	0.73	15.02
Public mobility	0.36	0.02	0.00	14.19	1.71	0.47	8.85

Table 87 Daily external costs in euro-cent related to airborne pollutant emissions from private and public mobility after the lockdown

After the lockdown, considering the same CO_2 it is possible to see how it starts to increase, passing from 8.59 cent (during lockdown) to 15.02 cent for the private mobility and from 2.61 to 8.85 cent for the public mobility.

Figures from Figure 36 to Figure 42 show the costs reported in the histograms to better understand the comparison between the three different periods and how the costs decreased during lockdown.

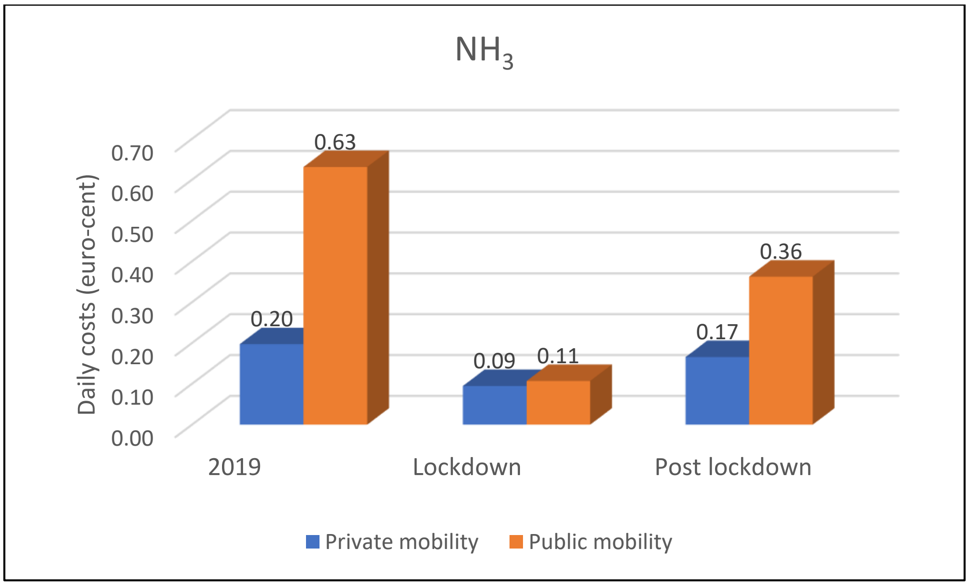

Figure 36 Daily external costs of NH_3 for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

For the ammonia pollutant it is possible to see the decrease during the lockdown. Daily costs for private mobility show 0.2 cent during 2019, 0.09 cent during lockdown and 0.17 cent after the lockdown; daily costs for public mobility show 0.63 cent during 2019, 0.11 cent during lockdown and 0.36 cent after the lockdown. In particular for this pollutant the costs for the public mobility are higher than the costs for the private mobility since the emission factor of public mobility is higher.

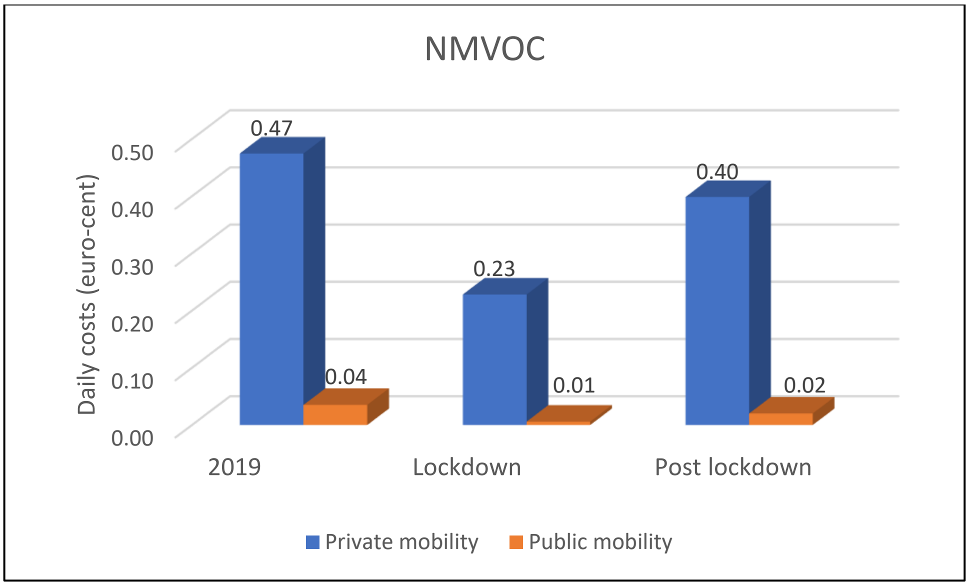

Figure 37 Daily external costs of NMVOC for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

For the non-methane volatile organic compounds, it is possible to see the decrease during the lockdown. Daily costs for private mobility show 0.47 cent during 2019, 0.23 cent during lockdown and 0.40 cent after the lockdown; daily costs for public mobility show 0.04 cent during 2019, 0.01 cent during lockdown and 0.02 cent after the lockdown.

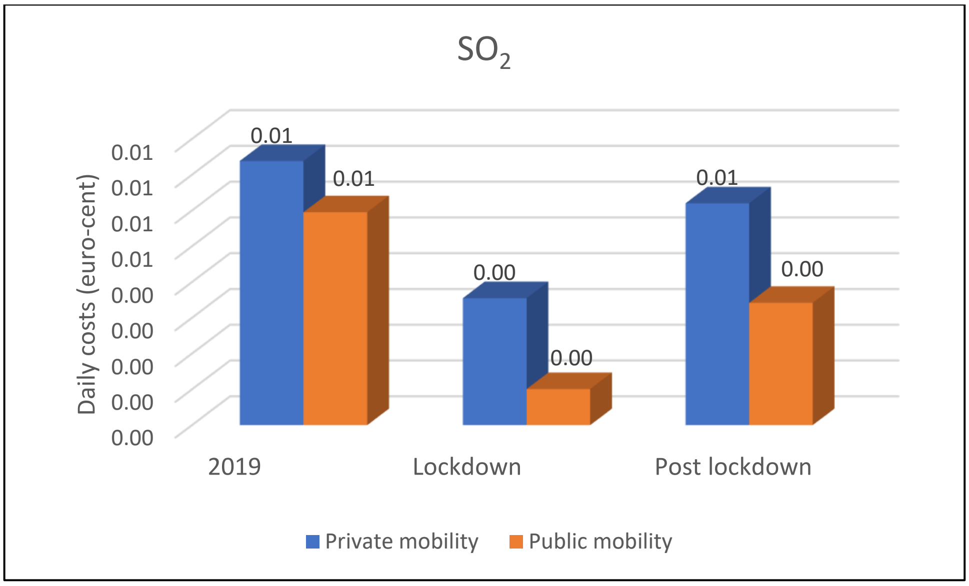

Figure 38 Daily external costs of SO_2 for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post- lockdown)

For sulfur dioxide pollutant it is possible to see the decrease during the lockdown. Daily costs for private mobility show 0.01 cent during 2019, 0.00 cent during lockdown and 0.01 cent after the lockdown; daily costs for public mobility show 0.01 cent during 2019, 0.00 cent during lockdown and 0.00 cent after the lockdown.

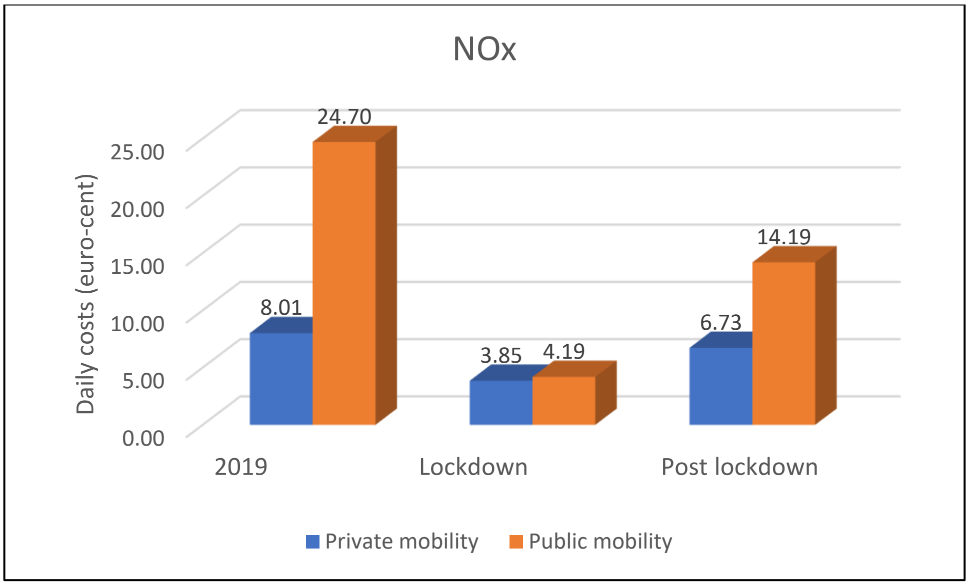

Figure 39 Daily external costs of NO_x for each transport mode (private and public mobility) and for each period considered (2019, during lockdown, post-lockdown)

For NO_x pollutant it is possible to see the decrease during the lockdown. Daily costs for private mobility show 8 cent during 2019, 3.85 cent during lockdown and 6.73 cent after the lockdown; daily costs for public mobility show 24.7 cent during 2019, 4.19 cent during lockdown and 14.19 cent after the lockdown. In particular for this pollutant the costs for the public mobility are higher than the costs for the private mobility since the emission factor of public mobility is higher.

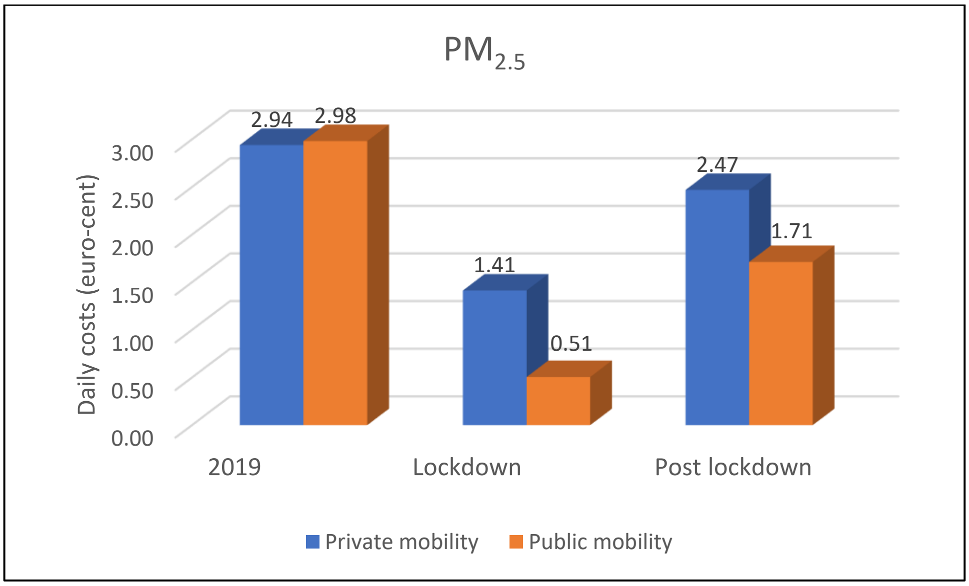

Figure 40 Daily external costs of $PM_{2.5}$ for each transport mode (private and public mobility) and for each period considered (2019, during lockdown, post-lockdown)

For $PM_{2.5}$ pollutant it is possible to see the decrease during the lockdown. Daily costs for private mobility show 2.94 cent during 2019, 1.41 cent during lockdown and 2.47 cent after the lockdown; daily costs for public mobility show 2.98 cent during 2019, 0.51 cent during lockdown and 1.71 cent after the lockdown.

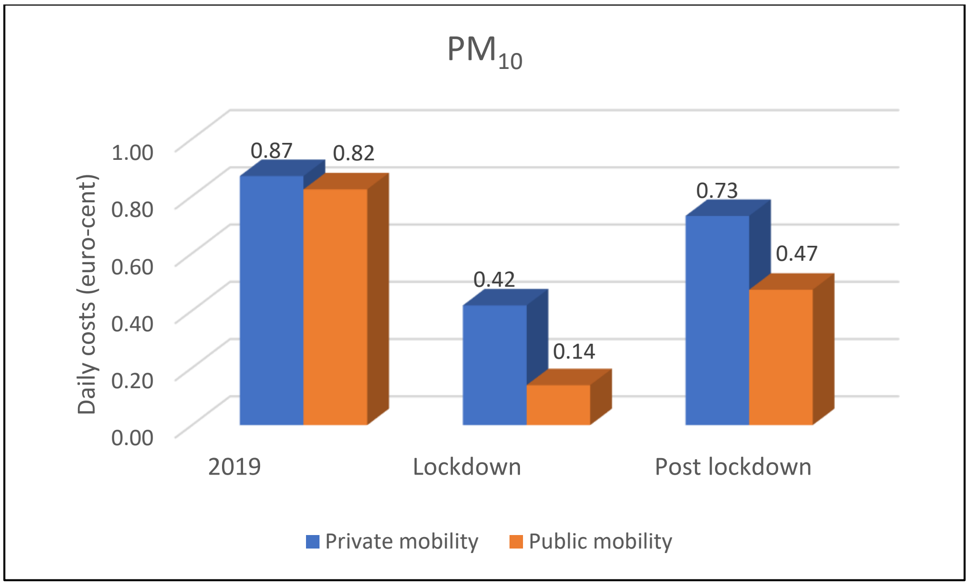

Figure 41 Daily external costs of PM_{10} for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

For PM_{10} pollutant it is possible to see the decrease during the lockdown. Daily costs for private mobility show 0.87 cent during 2019, 0.42 cent during lockdown and 0.73 cent after the lockdown; daily costs for public mobility show 0.82 cent during 2019, 0.14 cent during lockdown and 0.47 cent after the lockdown.

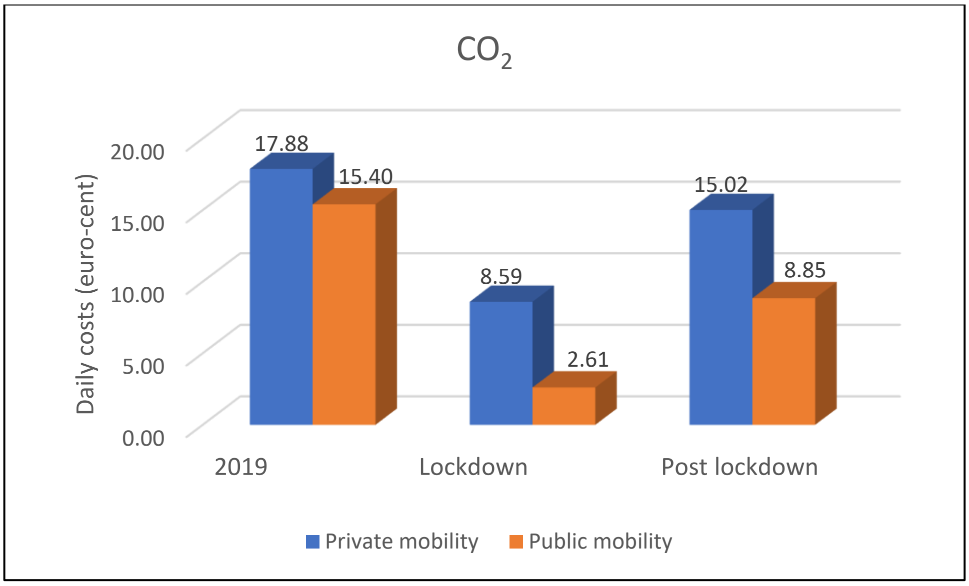

Figure 42 Daily external costs of CO_2 for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

For CO_2 pollutant it is possible to see the decrease during the lockdown. Daily costs for private mobility show 17.88 cent during 2019, 8.59 cent during lockdown and 15 cent after the lockdown; daily costs for public mobility show 15.4 cent during 2019, 2.61 cent during lockdown and 8.85 cent after the lockdown.

Furthermore, by having calculated the number of daily millions of passengers per kilometer for each transport mode and for the three different periods and by having the average external costs expressed in euro-cent per pkm it is possible to obtain the daily average external costs in Italy for the three different periods, related to accident, air pollution, climate change, noise, well to tank and habitat damage. Tables from Table 88 to Table 93 show the results.

Daily average external costs-accidents (€)					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
33.74	0.73	5.29	0.04	23.73	0.35

Table 88 Daily average external costs related to accidents for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

For the daily average external costs related to accidents, it is possible to see that for the private mobility there is the decrease from 33.74 euros to 5.29 euros with the consequent increase after the lockdown to 23.73 euros. For the public mobility there is the decrease from 0.73 to 0.04 euros during lockdown and the consequent increase to the value of 0.35 euros after the lockdown.

Daily average external costs-air pollution (€)					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
5.66	1.14	0.89	0.06	3.98	0.55

Table 89 Daily average external costs related to air pollution for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

For the daily average external costs related to air pollution, it is possible to see that for the private mobility there is the decrease from 5.66 euros to 0.89 euros with the consequent increase after the lockdown to 3.98 euros. For the public mobility there is the decrease from 1.14 to 0.06 euros during lockdown and the consequent increase to the value of 0.55 euros after the lockdown.

Daily average external costs-climate change (€)					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
8.65	0.60	1.36	0.03	6.08	0.29

Table 90 Daily average external costs related to climate change for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

For the daily average external costs related to climate change, it is possible to see that for the private mobility there is the decrease from 8.65 euros to 1.36 euros with the consequent increase after the lockdown to about 6 euros. For the public mobility there is the decrease from 0.6 to 0.03 euros during lockdown and the consequent increase to the value of 0.29 euros after the lockdown.

Daily average external costs-noise (€)					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
6.90	1.01	1.08	0.06	4.85	0.49

Table 91 Daily average external costs related to noise for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

For the daily average external costs related to noise, it is possible to see that for the private mobility there is the decrease from 6.9 euros to about 1 euro with the consequent increase after the lockdown to 4.85 euros. For the public mobility there is the decrease from 1 to 0.06 euros during lockdown and the consequent increase to the value of 0.49 euros after the lockdown.

Daily average external costs-well to tank (€)					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
3.01	0.26	0.47	0.01	2.12	0.12

Table 92 Daily average external costs related to well to tank for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

For the daily average external costs related to well to tank, it is possible to see that for the private mobility there is the decrease from 3 euros to 0.47 euros with the consequent increase after the lockdown to 2 euros. For the public mobility there is the decrease from 0.26 to 0.01 euros during lockdown and the consequent increase to the value of 0.12 euros after the lockdown.

Daily average external costs-habitat damage (€)					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
3.07	0.15	0.48	0.01	2.16	0.07

Table 93 Daily average external costs related to habitat damage for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

For the daily average external costs related to habitat damage, it is possible to see that for the private mobility there is the decrease from 3 euros to 0.48 euros with the consequent increase after the lockdown to about 2 euros. For the public mobility there is the decrease from 0.15 to 0.01 euros during lockdown and the consequent increase to the value of 0.07 euros after the lockdown.

Figures from Figure 43 to Figure 48 show the results through some histograms in order to understand how much the average external costs have been decreased during the period of lockdown.

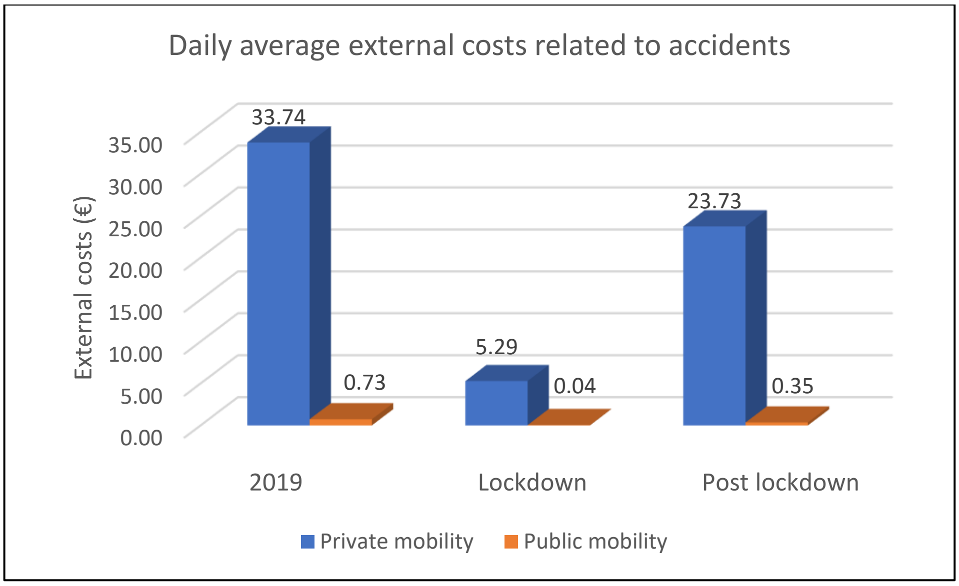

Figure 43 Daily average external costs related to accidents for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

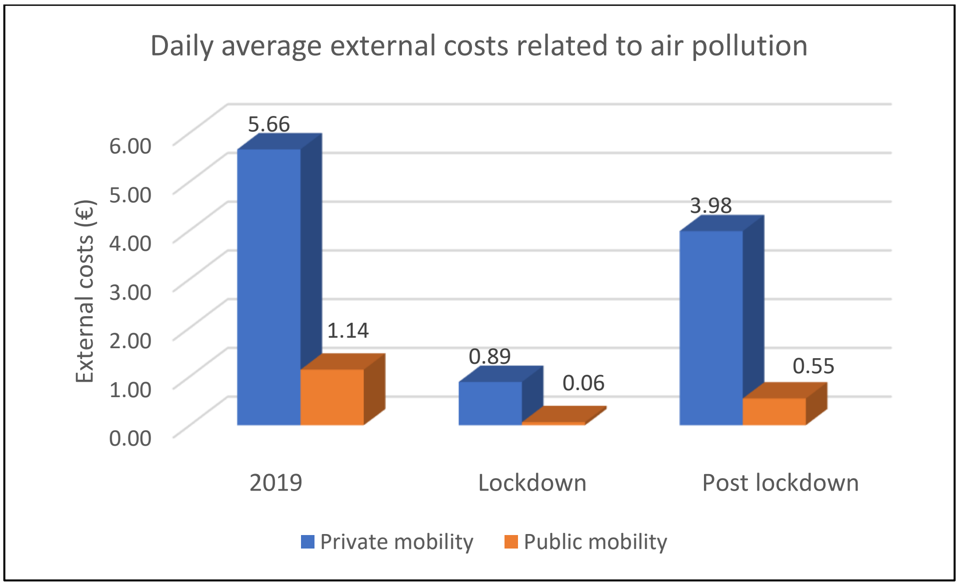

Figure 44 Daily average external costs related to air pollution for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

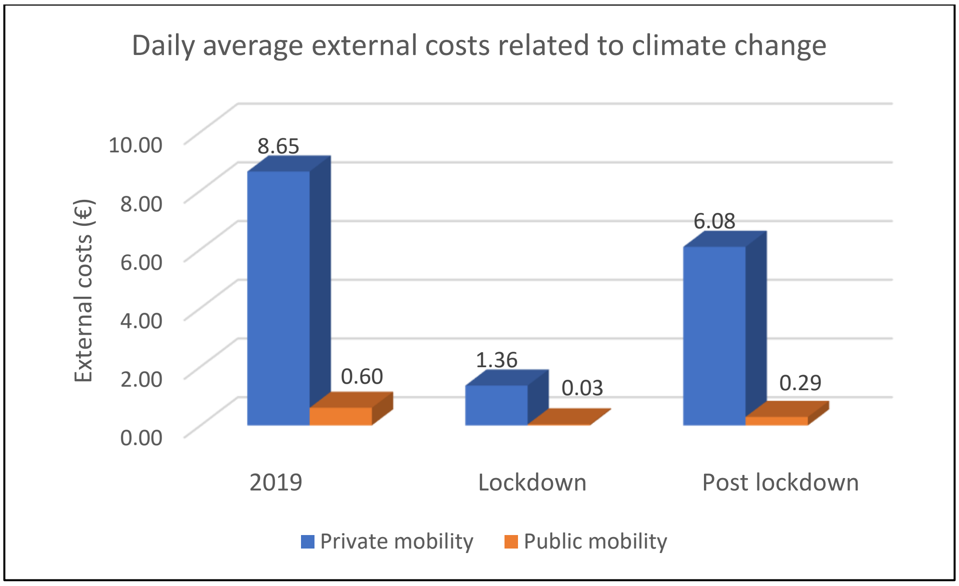

Figure 45 Daily average external costs related to climate change for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

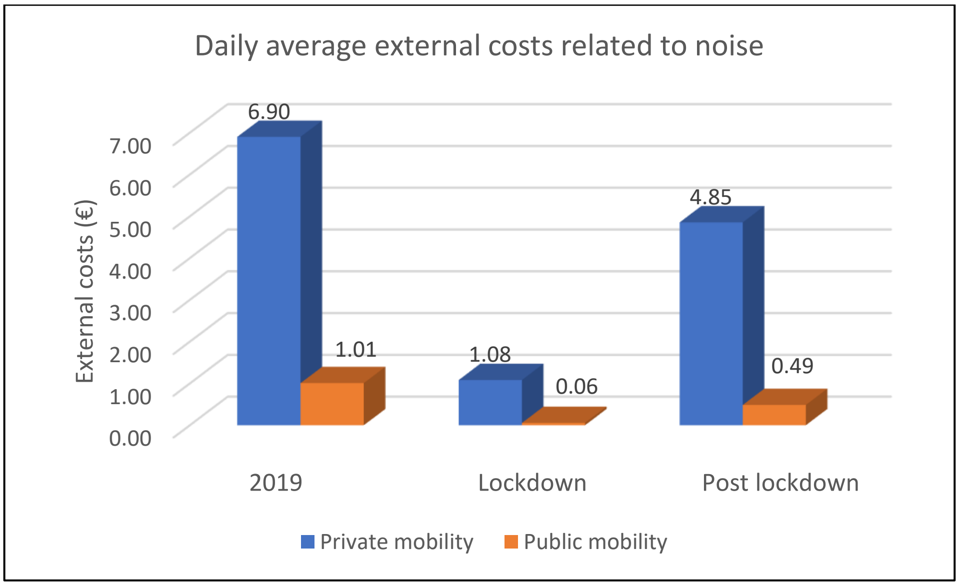

Figure 46 Daily average external costs related to noise for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

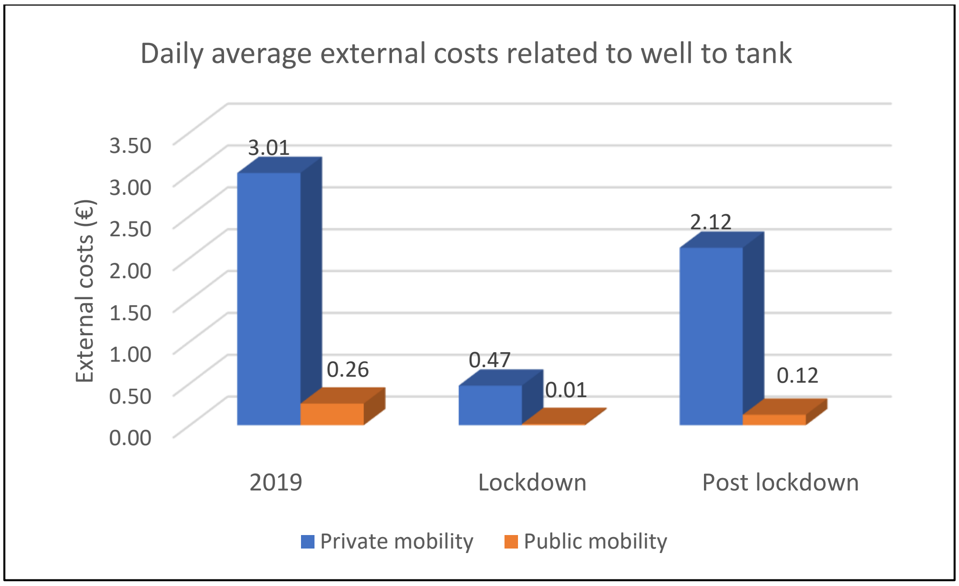

Figure 47 Daily average external costs related to well to tank for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

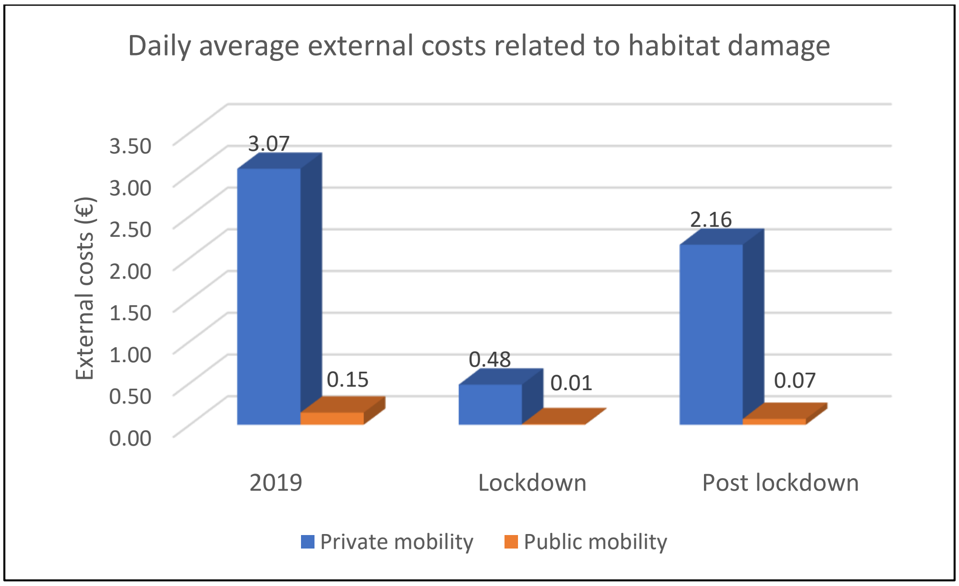

Figure 48 Daily average external costs related to habitat damage for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

Table 94 shows the total daily external costs including accidents, air pollution, climate change, noise, well to tank and habitat damage.

Total daily average external costs(€)					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
61.02	3.88	9.56	0.21	42.93	1.87

Table 94 Total daily average external costs for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

Figure 49 shows the total daily average external costs for the three different periods taken into consideration (2019, lockdown and post lockdown) for each transport mode.

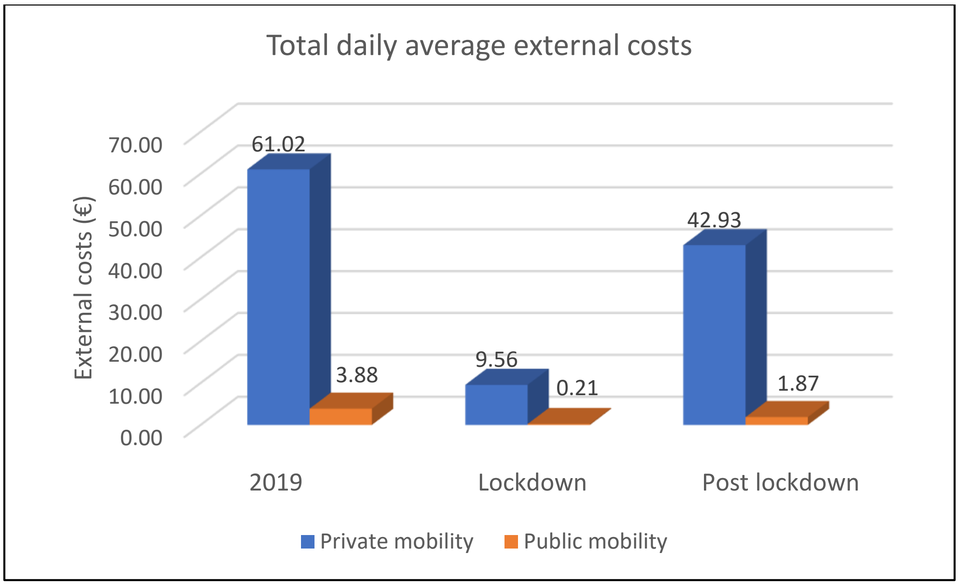

Figure 49 Total daily average external costs for each transport mode (private and public mobility) and for each period considered (2019, lockdown, post-lockdown)

The year 2019 shows that each day are spent 61 euros for the private mobility and about 4 euros for the public mobility. During the lockdown (from12/03/2020 to 03/05/2020) 9.56 euros are spent for the private mobility and 0.21 for the public mobility. This means that during lockdown period the costs decreased. After lockdown (from 18/05/2020 to 15/10/2020) 43 euros are spent for the private mobility and 1.9 euros are spent for the public mobility, showing the increase after the period of lockdown.

In conclusion it is possible to understand the contribution of each transport mode in percentage with respect to the sum of the two transport modes.

Table 95 shows the sum of private and public mobilities for each period: 2019, during lockdown and post lockdown.

Total daily average external costs (€)		
2019	from 12/03/2020 to 03/05/2020	from 18/05/2020 to 15/10/2020
Private + public mobilities	Private + public mobilities	Private + public mobilities
64.91	9.78	44.79

Table 95 Total daily average external costs for each period considered (2019, lockdown, post-lockdown)

Table 96 represents the contribution of each transport mode to the total of each period analyzed.

Contribution of each transport mode on the total daily average external costs (%)					
2019		from 12/03/2020 to 03/05/2020		from 18/05/2020 to 15/10/2020	
Private mobility	Public mobility	Private mobility	Public mobility	Private mobility	Public mobility
94.02	5.98	97.81	2.19	95.83	4.17

Table 96 Contribution of each transport mode for each period considered (2019, during lockdown, post-lockdown)

It is interesting to show that the percentage of the private mobility increase during lockdown (from 94 to 97%) and that the percentage of the public mobility decreases during lockdown (from 5.98 to 2.19%).

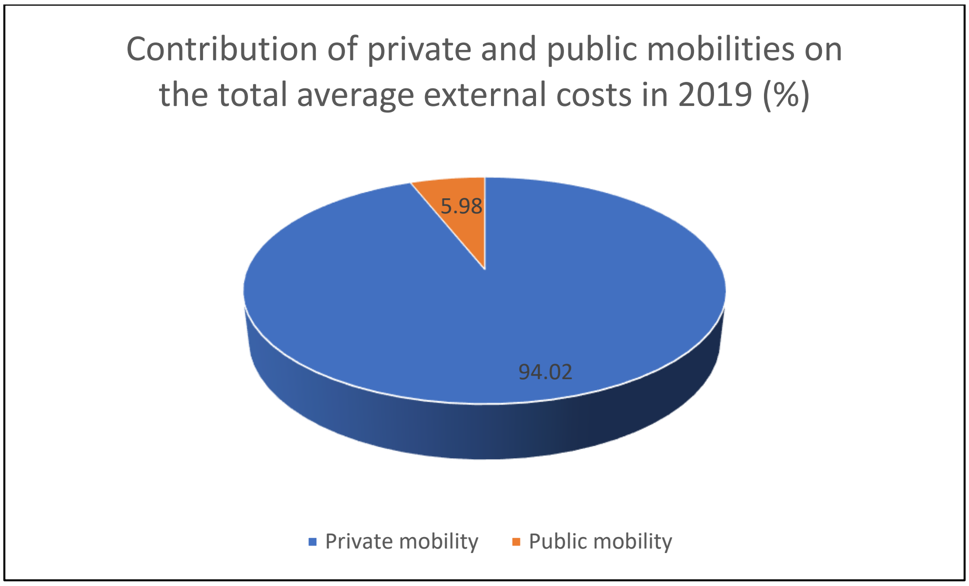

Figure 50 Contribution of private and public mobility on the total average external costs in 2019

In the year 2019 the contribution of the private mobility on the total average external costs is 94.02 % and the public mobility corresponds to 5.98%.

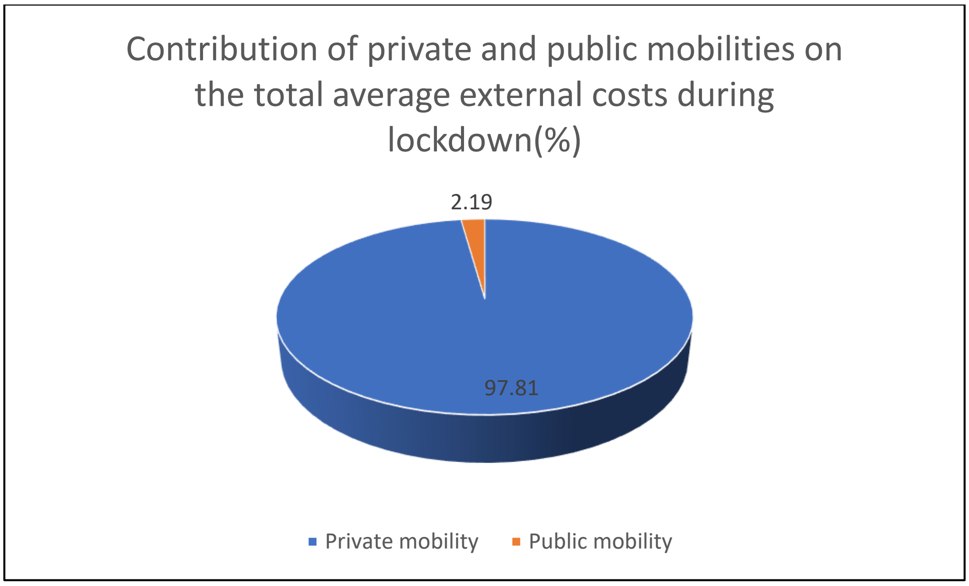

Figure 51 Contribution of private and public mobility on the total average external costs during lockdown

During the lockdown the contribution of the private mobility on the total average external costs is 97.81 % and the public mobility corresponds to 2.19%. It means that the trend of the private mobility during the lockdown increases (from 94.02% to 97.81%) and that the trend of the public mobility during the lockdown decreases (from 5.98% to 2.19%).

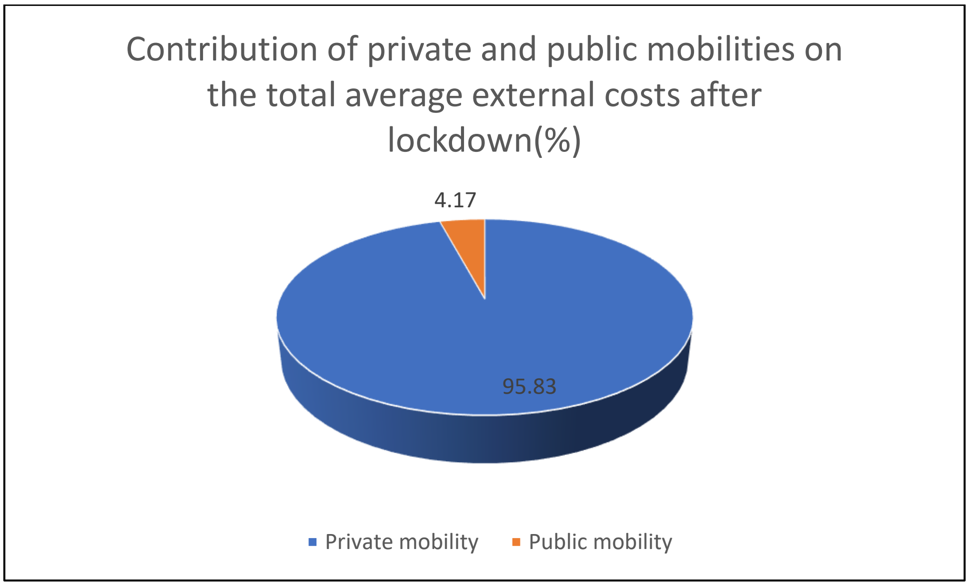

Figure 52 Contribution of private and public mobility on the total average external costs after lockdown

After the lockdown, the trend is quite similar to the trend of the 2019 showing 95.83% of the private mobility and 4.17% of the public mobility on the total average external costs.

4. CONCLUSIONS

In the first part of the work proxy values have been calculated. In particular the proxy related to the ratio of the population and the extent of roads has been considered in order to correlate the mobility of passenger per kilometer of each area of Italy and of each region of each area of Italy. With the emission factors and the vehicles per kilometer it was possible to obtain the grams and then the kilograms per kilometer for each pollutant for each area of Italy and for each mobility referred to the year 2019.

The second part of the work is related to the influence of Covid-19 on mobility and then, to airborne pollutant emissions. The Covid-19 pandemic has affected daily lives of almost all countries. Italy was perceived as most affected in Europe by the Covid-19 epidemic. Although the situation in Europe has yet to stabilize, Italy is attempting to recover from this crisis as soon as possible (Xiao, 2020).

Mobility was partly responsible for the rapid development of the epidemic. Both short and long-distance travel caused the virus spread to increase dynamically. The lockdown caused a sharp reduction in the number of trips and distance traveled. Covid-19 influenced the number of millions of daily passengers per kilometer and the average length of daily trips. Taking into consideration the emission factors and the average length of daily trips, it was possible to obtain the daily emission of different airborne pollutants NH_3, NMVOC, SO_2, NO_X, $PM_{2.5}$, PM_{10} and CO_2 for private and public transport modes and for each period (during 2019, during lockdown and after the lockdown). Then, by considering the average external costs it was possible to obtain the costs related to each pollutant, showing the important decrease during the period of lockdown (from 12/03/2020 to 03/05/2020) and the consequent increase after the lockdown (from 18/05/2020 to 15/10/2020).

Furthermore, the daily average external costs were obtained for Italy based on the number of daily millions of passengers per kilometer for private and public transport modes and for the three different periods. Specifically, the external costs considered are related to accidents, air pollution, climate change, noise, well to tank and habitat damage attributable to road transport. Results showed an effective reduction of the external costs during the lockdown period and the following increase after the lockdown.

In conclusion it was possible to understand the contribution of each transport mode in percentage with respect to the sum of the two transport modes. It was interesting to notice that the percentage of private mobility increased and the percentage of public mobility decreased during lockdown.

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