Towards the Evaluation of Carbon Footprint for University Communities' Mobility: Challenges, Opportunities, and Reduction Strategies

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***Abstract*— One of the reasons for the increase in the global average temperature is undoubtedly the emission of greenhouse gases by various sectors, especially from the transportation sector, which accounts for 24 percent of these global emissions. Academic institutions, through student mobility, contribute substantially to their overall environmental footprint, with 0.3 tons of CO_2 equivalent per person per year.**

One of the crucial challenges is to estimate the student demand. For this purpose, in this paper, a Mixed Gravity Model is proposed by combining socio-economic aspects with the efficiency of public transport. The model shows good prediction accuracy by comparing the actual number of students and the estimated number of students (Pearson coefficient assumes the value of P=0.9418). With this tool, it is possible to forecast future scenarios, implement new reduction strategies, set new challenges, and provide new opportunities to reduce carbon footprint for the whole University community.

Keywords*—*Carbon footprint evaluation; University communities' mobility; Sustainable Mobility; Gravity Models.

I. INTRODUCTION

With the increase in the global average temperature of 1 ºC, the problem of climate change has become one of the most critical challenges of this century.

One of the reasons for this increase is undoubtedly the emission of greenhouse gases by various sectors, including transportation, which accounts for 24 percent of these global emissions [1]. Academic institutions, through student mobility, contribute substantially to their overall environmental footprint [2].

In this context, the University of Jyväskylä [1] studied its carbon footprint from mobility and transport, highlighting that students contribute 0.3 tons of CO_2 equivalent per person per year. The results indicate that most emissions are generated by car use, suggesting the need for policies to promote low-impact transport options.

However, the transport sector is constantly changing, especially as regards how users travel.

Significant changes have occurred since the COVID-19 pandemic which had an unprecedented impact on global mobility.

The restrictions introduced have significantly affected travel demand and the modal choice of users, in particular the academic population, leading them to prefer private modes rather than shared modes [3].

In addition to the problem of the pandemic, the different habits caused by territorial influence are also

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jeopardising the path towards sustainable mobility, fuelling the problem of environmental pollution and therefore CO_2 emissions into the atmosphere. Henke et al. [4] investigate the mobility habits of university students in Southern Italy, revealing a preference for private car use due to the poor quality of public transport and the availability of free parking. Their study suggests that improving public transport accessibility and promoting carpooling could play a crucial role in promoting more sustainable travel behaviour among students.

Technological innovations have also played a key role in transforming the mobility landscape.

The development of specific tools to assess the CO_2 emitted from the transportation sector allows mobility managers to understand how important it is to prefer more sustainable modes of transportation [5-8].

Given these transformations, this article aims to develop existing literature by examining the current state of travel demand and mobility preferences.

Through the elaboration and creation of a gravity model to estimate the number of students that make trips to reach the University, located in central Italy, and their spatial distribution, the paper aims to assess the impact of risk mitigation measures [9-11] and the availability of sustainable travel options and the inefficiency of public transport.

In addition, the study could be used to investigate the potential to promote sustainable mobility practices through targeted policies and technological innovations.

II. METHODOLOGY

A. Hybrid Gravity model

Estimating the demand is crucial to analyse, improve, and make project proposals for a transport system. Several features influence the demand and their relationships could be tricky to highlight in a complex space of analysis. In general, a demand model could be defined as a mathematical relationship that allows to evaluate the demand, as suggested in Eq. 1 below [12]:

$$d_{od}[k_1 \ldots k_n] = d\,(SE, T, \beta) \quad (1)$$

Where $k_1 \ldots k_n$ are the characteristics of the travel zone, while SE, T, β represent the socioeconomic variables of households; the vector of the level of service variables (times, travel costs, etc.); the vector of the calibration parameters, respectively.

Going to the matter, as proposed according to the current scientific literature, the demand could be estimated by using Four Stage Models (FSM) [12].

$$d^i(h,s,o,d,m,k) = n^i(o)\,p^i(x/osh)\,p^i(d/osh)\,p^i(m/dosh)\,p^i(k/mdosh) \quad (2)$$

Where:

- $n^i(o)p^i(x/osh)$ is the generation model;
- $p^i(d/osh)$ is the distribution model;
- $p^i(m/dosh)$ is the modal choice model;
- $p^i(k/mdosh)$ is the route choice model.

The generation model estimates the number of trips in the period h for the reason s by the generic user belonging to category i with origin in the area o [12].

A distribution model allows to estimate the number of trips made by users belonging to category i who, starting from the area or for reason s in period h, go to destination d [12].

With a modal choice model, it is possible to retrieve the probability that the individuals belonging to category i who, moving from the origin or destination d, for the reason s, in the period h, choose the mode of transport m [12].

The purpose of a route choice model is to estimate the probability that individuals of category i who, moving between o and d, for the reason s, in the time slot h and with the mode m, choose the path k [12].

Regarding the investigation of the distribution of trips, several models could be used [12], but one of the most common is the Gravity Model [13]. According to Sosslau et al. [13-15], these models are based on the simplified assumption that the trips generated from an area are attracted from other areas according to the attractive power of the zone and the travel impedance between the areas (expressed with travel times or distances). Gravity Models are derived from Newton's Law of Gravity [15], and by specifying this law in the context of estimating trip distribution, is possible to obtain that:

$$F_{od} = K\frac{G_o^{\alpha} A_d^{\beta}}{D_{ij}} \quad (3)$$

Where:

- F_{od} is the estimated flow from the areas of origin o and the area of destination d;
- G_o^{α} is the emission potential or trip production value from the origin area o;
- A_d^{β} is the attraction value of the destination area d;
- D_{ij} is the distance between the origin o and the destination d of the trip;
- K is a constant value in the gravity model;
- α and β are the parameters of the model to calibrate [16].

B. Evaulation of Transport Externalities: Carbon footprint

The concept of sustainable mobility aims precisely to reduce the causes of environmental pollution and to

achieve an increasingly green and less polluted environment.

Policies such as carpooling, incentives for the use of public transport, and, in general, sustainable modes, are designed to tackle this problem.

Among the various advantages that are found, the use of shared vehicles leads to a significant reduction in CO_2 emissions in the atmosphere, reducing the so-called carbon footprint.

To assess the carbon footprint of different modes of transport and thus be able to address the relevant emission levels, it is necessary to refer to the methodology adopted by tools of Italian public transport companies.

This method is called ETW (EcoTransITWorld) and first provides for the calculation of energy consumption, then defines the fuel mixture of the medium, and evaluates the amount of CO_2 emission expressed in terms of CO_2 equivalent.

Referring to the train as a mode of public transport, an example of a procedure to evaluate the carbon footprint is proposed.

The energy consumption (E^3) was evaluated [5]:

$$E^3 = 1200 * M_t^{-0.62} * q \ [kJ/gross - tonnekm] \quad (4)$$

Where:

Mt is the train's gross mass;

q is the trip altitude difference.

Then it is possible to evaluate the total energy consumption (E3TTW) [5]:

$$E^3_{TTW} = \frac{1}{r} * E^3 * M_{tl} * 3.6 * 10^{-3} [MJ] \quad (5)$$

Where:

- r is the train space utilization rate;
- E^3 is the energy consumption that was calculated in the previous step;
- M_{tl} is the maximum train load.

The amount of CO_2 emissions is also affected by energy losses in the traction grid and high-voltage transmission lines.

To take this into account, it is essential to know the type of catenary system installed (γ).

It's fundamental to reconsider the energy source and the type of fuel (k) in question.

It is therefore possible to evaluate the intensity of CO_2 emitted per unit of energy [5]:

$$\theta\,(\omega(ts^j_k)) = \frac{\delta(k)*\beta(k)*1000}{\alpha(k)} * \frac{1}{\omega(ts^j_k)} * \frac{1}{100} [gCO2/kWh] \quad (6)$$

Where:

- δ(k) is the calorific value;
- β(k) is the CO_2 emissions produced from the
- k-type of fuel;
- α(k) is the energy generated from the fuel;
- $\omega(ts^j_k)$ is the efficiency of a powerhouse.

So finally, the intensity of CO_2 emissions can be assessed as [5]:

$$F^{gross}_{b,y,i,k,j} = E^i_{TTW} * \theta\,(\omega(ts^j_k)) * \frac{(1+\gamma)}{d * M_t} \left[\frac{gCO2}{gross\text{-}tkm}\right] \quad (7)$$

As regards the evaluation of CO_2 emitted by road transport, the following rearranged equation (Eq.8) can be used [17]:

$$E_m = \frac{D_{i,j}}{C_{i,j}} * Ef_{i,j} \quad (8)$$

Where:

- E_m is the total carbon emission (gCO_2);
- $D_{i,j}$ is the travel distance (Km);
- $C_{i,j}$ is the load factor (person);
- $Ef_{i,j}$ is the emission factor (g/Km)

As far as the evaluation of $Ef_{i,j}$ is possible to refer to data of literature [18,19].

III. CASE STUDY

The University of Cassino and Southern Lazio is made up of several campuses located in the cities of Cassino, Frosinone, Atina, and Gaeta.

In the Municipality of Cassino, the vast majority of academic centers are located: the Rectorate, the campus (which houses the Faculties of Economics and Law, Humanities, Social Sciences, and Health) and student accommodation in the Folcara area; while in Gaetano di Biasio street the Faculty of Engineering and in Zamosch Street the Department of Humanities (see Fig.1).

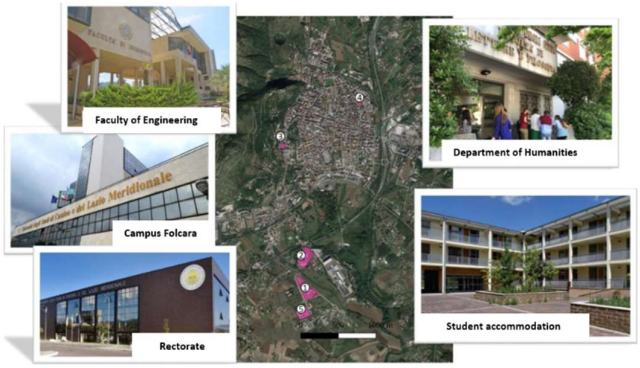


Figure 1: Location of the University of Cassino

It is necessary to evaluate the transportation supply in the area to reconstruct a cognitive picture of the infrastructures (road network, cycle-pedestrian paths, rest areas, interchange nodes) and transport services that can

be used by students as part of their home-study journeys. It is particularly important to analyse the public and shared transport offered in the local context.

To better satisfy the presentation of the current transport supply in the Cassino area, it was decided to analyze the entire Municipality of Cassino (total area of 83.42 km^2 with about 36000 inhabitants) and not the areas of influence of 500m from each Department or Faculty (see Fig.2).

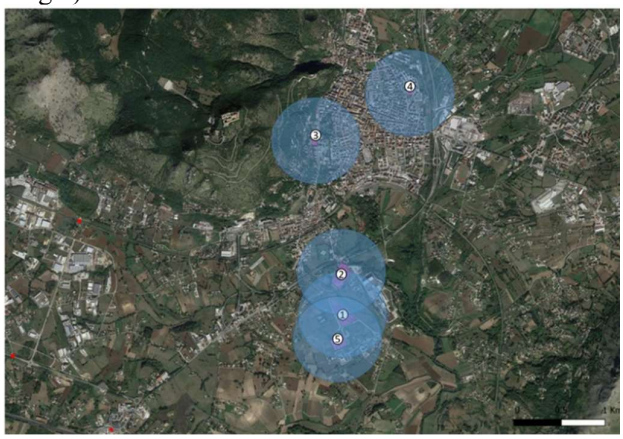


Figure 2: Areas of influence around the university premises in the territory of Cassino.

The territorial and urban structure of the Municipality of Cassino is composed of an urban center with three hamlets: San Bartolomeo, Sant'Angelo in Theodice and Caira (see Fig.3).

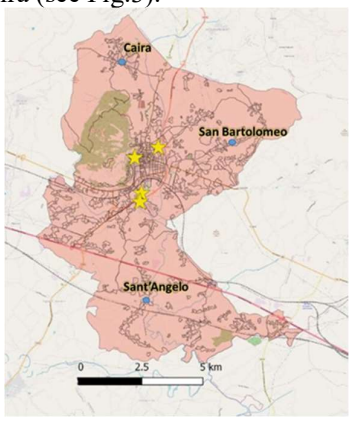


Figure 3: Hamlets of the town of Cassino.

The distribution of services of collective interest in the hamlets is limited to basic services, such as schools, while the main administrative and civic services are variously located in the main urban center. Most of the poles of attraction (schools, universities, public services and offices, cultural, recreational and sports facilities, administrative services, and services of collective interest) are located in the central area.

The interchange flows between Cassino and the neighboring towns take place through two main connections, represented by the SS6 Casilina Nord and Casilina Sud and the Regional Road 630 Sora-Cassino-Formia. Of particular interest for the influx of road users is the A1 motorway exit (Autostrade del Sole) connected to the SR 630. Therefore, cord nodes can be identified, each of which will be called upon to perform a specific function, both for its position and for the existing infrastructures (see Fig.4).

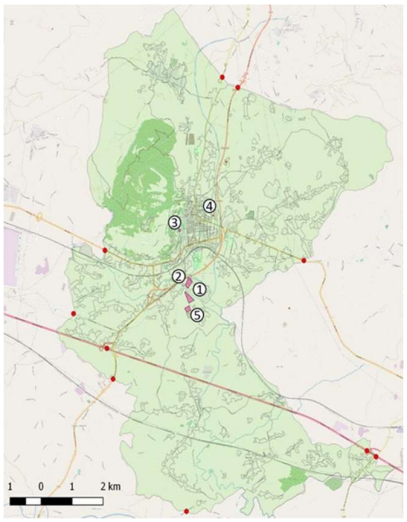


Figure 4: Cordon knots for city access.

The city of Cassino is served by the Rome-Cassino-Naples railway line consisting of an electrified double-track network (see Fig.5).

Cassino station is located in a strategic position as it allows people to easily reach the city center and the hamlets. This is an average of one kilometer from the various universities.

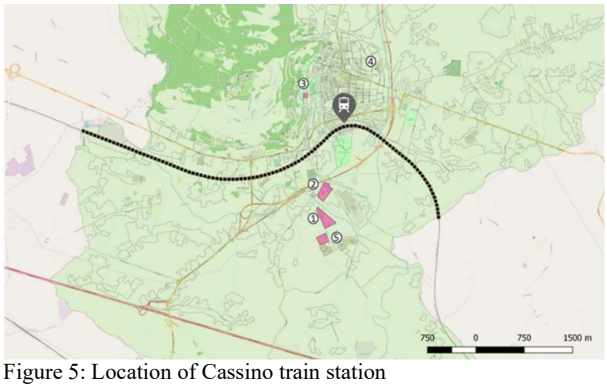


Figure 5: Location of Cassino train station

The local Transit system serving the city consists only of Local Public Transport (LPT) by road. In particular, the urban service is managed by two different companies: Magni and Mastrantoni. The first company operates the service with 18 urban lines while those related to the Mastrantoni company are 7 lines that connect the city center with the peripheral localities such as San

Bartolomeo, Caira, and Sant'Angelo, the SS. Scolastica hospital and Montecassino.

The suburban connections are carried out by the transport company Cotral Spa.

For the active student population only (with at most only one year out of course), the spatial distribution of the residences is shown below (see Fig.6).

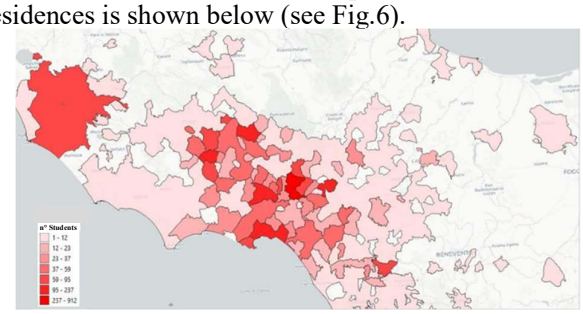


Figure 6: Spatial distribution of student residences

IV. RESULTS

As already described in the "Methods" section, Gravity Models are useful tools to predict both the number of trips that are made and their spatial distribution. In the current section, a Mixed Gravity Model is proposed. With this tool, by knowing the population of the origin area, the level of inefficiency of Public Transport, and the total number of students in the province, it is easy to evaluate the number of students that come from a certain origin area and reach the University. In addition to that, by improving the efficiency of Public Transport, different future scenarios could be evaluated to estimate the new student demand or address new academic policies to make strategies, set new challenges, and give opportunities to potential students. In Eq. 9 and Eq. 10, the model is described:

$$k_{ij} = \frac{\frac{NU_i}{\left(k_{TPL_{ij}} \cdot d_{ij}\right)^{\alpha}}}{\Sigma_i \frac{NU_i}{\left(k_{TPL_{ij}} \cdot d_{ij}\right)^{\alpha}}} \quad (9)$$

$$NS_{ij} = NS_{tot} \frac{\frac{P_i \cdot k_{ij}}{\left(k_{TPL_{ij}} \cdot d_{ij}\right)^{\alpha}}}{\Sigma_i \frac{P_i \cdot k_{ij}}{\left(k_{TPL_{ij}} \cdot d_{ij}\right)^{\alpha}}} \quad (10)$$

Where:

- NS_{ij} represents the number of students traveling from the j^{th} area to the Universities in the i^{th} destination province;
- NS_{tot} represents the total number of students in the i^{th} destination province;
- k_{TPLij} represents the level of inefficiency of the Public Transport the j^{th} area of origin to the Universities in the i^{th} destination province;
- k_{ij} represents the attraction factor from the j^{th} area to the Universities in the i^{th} destination province;
- d_{ij} represents the distance from the j^{th} area to the Universities in the ith destination province;
- N_{Ui} represents the number of Universities in the i^{th} destination province;
- α represents the main calibration parameter, which assumes the value of 0.8858.

As shown in Figure 7, the calibrated model can predict with a good grade of accuracy the number of students in the University: the Pearson coefficient assumes an acceptable value and shows good reliability (P=0.9418).

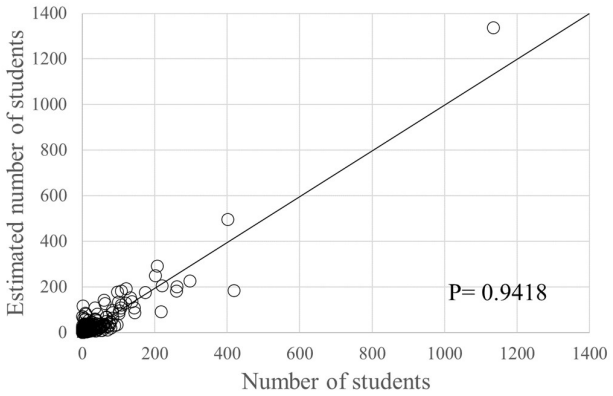


Figure 7: Comparison between the effective and estimated number of students.

V. CONCLUSION

The transport sector is one of the leading causes of pollution worldwide, contributing up to 24% of total greenhouse gas emissions. The main reasons that trips are made regard commuting purposes and among them, trips related to studying reasons. According to some authors [1], higher education students produce 0.3 tonnes of CO_2 equivalent per person per year.

To evaluate the demand of students who make their trips to reach the university, demand models are needed. In the context of Four Stage Models (FSM), Gravity Models are useful to evaluate not only how students will move (and so their spatial distribution) but also how many trips will be generated.

In this paper a Mixed Gravity Model is proposed: the novelty aspect regards the ability of this model to take into account the level of inefficiency of the public transport. Combining the information obtained from such models with the aforementioned methodologies to assess the carbon emission of a specific mode of transport, carbon footprint-oriented analysis could be carried out to assess how sustainable an academic community could be.

The purpose of this paper, as suggested in the title, is a preliminary step to find a way to set new challenges, give new opportunities, and plan reduction strategies to safeguard both the environment and student wellness: challenges to reduce the carbon footprint of students by improving the public transport and alternative mode of transport; new opportunities for students in terms of better accessibility to the university and greater inclusion to society.

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