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AN INSIGHT INTO TRAFFIC ANALYSIS WITH COMPUTER VISION
Leveraging Smart Infrastructure for Urban Traffic Flow Analysis

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KEYWORDS
Urbanisation
Cities
Public Space Management
Traffic Flow
Urban Lighting
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ABSTRACT
Urbanisation is accelerating, with the UN predicting 68% of the world population will live in cities by 2050, creating new challenges for public space management. Efficient traffic flow is essential in such environments. This project leveraged urban lighting infrastructure to deploy AI-powered edge computing devices with vision sensors on public light poles to monitor traffic at intersections. Three pilot sites in Cascais, Loures, and Oeiras featured nine intersections under real-world conditions. These smart devices not only provided valuable, continuous data for traffic analysis but also demonstrated the potential for resilient, cyber-safe, and connected infrastructures supporting the transition to smarter cities.

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1. Introduction

The United Nations predicts that by 2050, urban areas will be home to 68% of the global population (United Nations, Department of Economic and Social Affairs, Population Division, 2019). This affects how cities will have to organize and manage public spaces, as they accommodate distinct traits of human behavior, such as play, social interaction, creativity, economic activities, and entertainment. When planning new areas, many principles of sustainable development can be readily implemented given information is available to allow for informed decisions. However, this is more challenging in historic and consolidated areas.

Within urban contexts, public space plays a key role in making cities livable. Public space is not easy to define and has very different features and elements, depending on the cultural and geographical contexts. Public space is any place accessible to bring people together on a public basis. This includes public squares, marketplaces, monuments, parks, public beaches, riversides as well as pavements and streets.

It is not enough for a city to allocate ample space for public use, it also needs to ensure that the space is well-maintained and managed so that it can serve its purpose effectively. This raises further questions about the quality of the public space, such as how to make it safe and accessible to all users, and how to finance the costs of creating and maintaining such spaces.

Cities will use new technologies and innovation to deal with current and future problems in areas like transport and mobility or citizen engagement, making them become digital (or "smart"). Cities will also need to become more connected to timely use high-quality data to improve urban management and take quick corrective actions to mitigate any conflicts within the urban spaces (Department for Business, Innovation &Skills, 2013).

One of the main challenges that smart cities face is how to manage traffic congestion and improve mobility for their citizens. Traffic affects not only the efficiency and productivity of urban life, but also the environment, health, and safety of people. Therefore, it is crucial for smart cities to monitor and optimize traffic flow using innovative solutions based on data and technology.

In this work, we developed a prototype specifically designed for smart cities applications. This prototype, hosted in the public lighting infrastructure, measured traffic flow on key intersections of three municipalities in the Lisbon metropolitan area.

2. Methods

The traffic solution was tested in three different municipalities: Cascais, Loures, and Oeiras. Nine (9) locations were identified (L1-L9) with a total of seventeen (17) vision sensors deployed in the public light infrastructure (see Figure S1 in the Supporting Information section). With the objective of measuring the total traffic flow, three locations have energy available 24 hours per day (L1-3) and correspond to key intersections, where high traffic flow and conflicts are expected, particularly during rush hours. The other locations, L4-9, only have energy available during night (powered by switched grids) and correspond to single roads. These locations correspond to residential areas – or to accesses to residential areas – where the goal was to identify moments of potential excess of noise pollution.

Data was collected for two months (April and May) with random interruptions due to unexpected down time of the devices. Nevertheless, approximately 30 days of data was collected per device.

The vision sensors were connected to Jetson Xavier NX devices running jetpack 5.0.2 GA with all software deployed and managed via docker containers. Inferencing is done by a modified version of the YOLO-v7 model (Goulão et al., 2024; Novo et al., 2024) that was adapted for improved performance when feed with the top-down video streams, typical when sensors are deployed on lighting poles. The Deep SORT algorithm (Wojke et al., 2017) was used to track objects detected by the vision model. These objects are then counted when they cross a barrier that is configured for each camera perspective. For this purpose, we consider the sum of all vehicles (cars, buses, trucks, motorbikes, and bicycles).

2.1. Data analysis

All data analysis were performed using Python 3, processing blocks of one (1) hour and, since we have sparse data in some cases, median values were used.

Rush hours were defined using Tuesday, Wednesday, and Thursday data, as:

- Morning period: from 7 am to 9 am
- Afternoon period: from 4 pm to 7 pm

For the devices powered only at night:

- Early night period: from 9 pm to 11 pm
- Night period: from 2 am to 4 am
- Early morning period: from 5 am to 6 am.

3. Results and Discussion

With the solution deployed in the field, in the aforementioned locations, anonymized detections data were collected whenever the devices were powered. This meant full days for devices in locations L1 to L3 since they are on a permanent grid, and around 10 h per day for devices in locations L4 to L9, since they are on a switched grid tied to the public lighting schedule.

Our approach to evaluate traffic counting was done by calculating median values per hour per weekday (Figure 1 and S2).

4. Observations

Regarding image quality, one initial observation is that the lower visibility at night did not compromise the feasibility of the solution. It did degrade the camera's video stream quality, producing video frames with much more noise than during daytime, but still allowing for detections to take place. This image degradation was better or worse depending on the lighting conditions on each location, being that locations with High-Intensity Discharge (HID) lamps, especially sodium-based ones (both HPS and LPS) produced the most degraded streams.

Before diving into the details of the results, we observed some general trends that, although expected, should be mentioned.

1. There is a significant reduction in traffic volume during nighttime hours, a trend that aligns with expectations for residential zones and their access routes, such as those under study.
2. There is less traffic during weekends and holidays. This difference is smaller than the one observed between daytime and nighttime, but the trend is clear.
3. Rush hour traffic is very common in cities and their suburbs and quite noticeable from the gathered data across all locations. Data shows a peak in traffic volume for a period in the morning (from 7 am to 9 am) and in the afternoon (from 4 pm to 7 pm).

5. Comparing Locations

The comparison between traffic flow on different locations is a good source of information to understand the quality of our results and to highlight the diverse behaviours of traffic on different scenarios. Considering locations L1 to L3, we have:

- L1 is a national road that connects to the main accesses to and from the Lisbon metropolitan area, and as such is expected to have the highest traffic volume.
- L2 is a national/large road expected to have high volume of traffic, although less than in L1.
- L3 is a residential area and therefore should have the lowest traffic volume values.

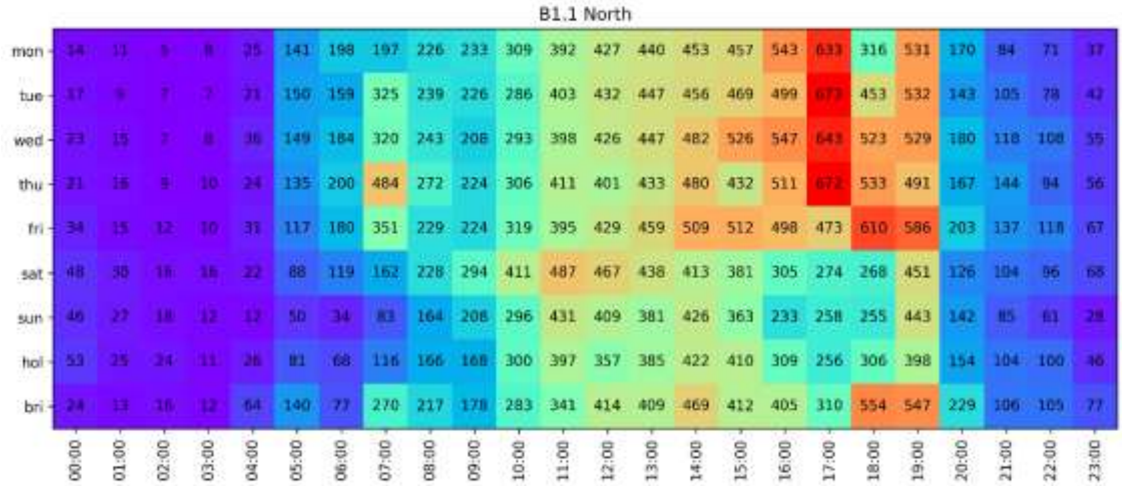
This difference in the scenarios is observed from our results, also validating the expectations as follows:

- L1 and L2 show peaks of traffic volume in the order of 600 to 1000 cars per hour, while in L3, the traffic volume values go beyond 500 only for barrier B3.3, being around 200 to 300 for all the others.

- Between, L1 and L2, the difference between high and low volume of traffic is also observed: barriers in L1, and barriers B2.1 and B2.3 show much larger traffic volumes than barrier B2.2, since this last one is already a tertiary road inside a residential area.
- The overall higher volumes are observed for L1.

Detailing further the residential area (L3) which includes a roundabout with four exits and a small intersection. The patterns observed here are heterogeneous between the barriers since we are monitoring several relatively small streets with high traffic. In addition, the camera perspectives are also heterogeneous for this location which might affect the obtained results (the evaluation of this effect is beyond the scope of this work). There are, however, some interesting details, that further support the quality of this solution. For example, on barrier B3.2 an abnormal peak is observed going North on Saturdays. This peak is similar to the values observed for the rush hour, although a bit later (the peak goes until 11am) which probably corresponds to cars going to the shopping centre that is located a few meters North from the roundabout.

Figure 1. Colour code representation of median values of traffic per hour for all weekdays ('hol' stands for national holidays and 'bri' for days between holidays and weekends). Colour code goes from blue (less cars) to green and red (more cars).



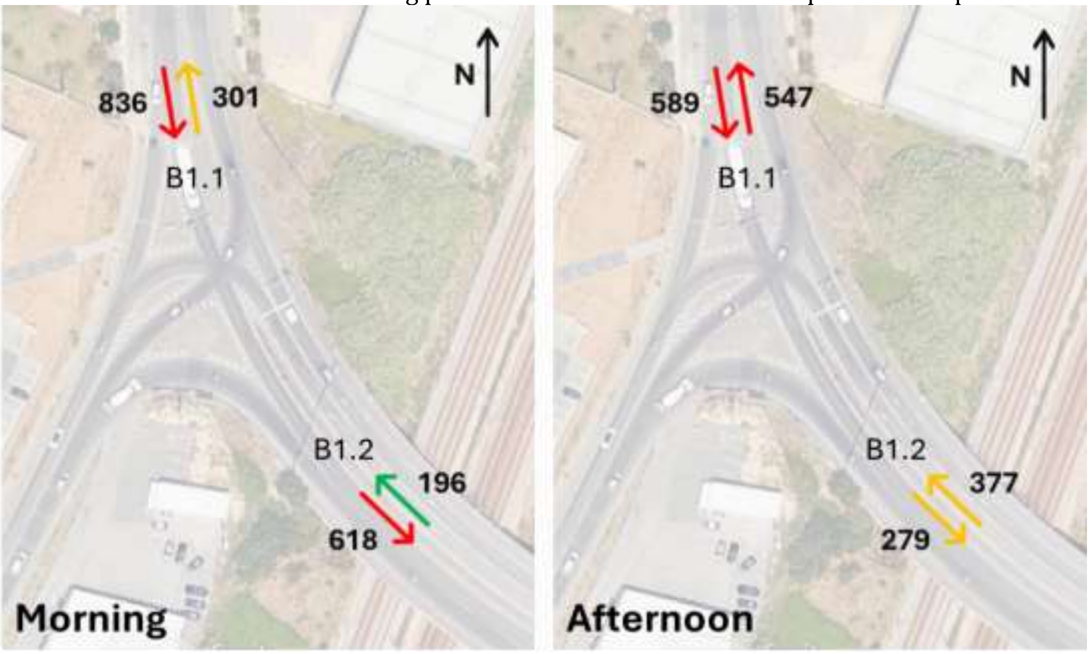
Source: Own elaboration, 2025.

6. Rush hour

Rush hour traffic is visible, in the morning and afternoon of weekdays, for all the barriers as indicated by the red zones in the heatmaps (example on Figure 1, more on Figure S2). This effect is more evident on Tuesdays, Wednesdays, and Thursdays probably because people commute from their homes nearer to their workplaces as opposed to Mondays and Fridays that, being closer to the weekends, allow people to travel to/from different places and/or at different times (for example, beach/country house).

The heatmaps data also shows that rush hour traffic typically changes from morning to the afternoon in the same place, but opposite direction. For example, for B1.1 North the red heatmap cells are in the afternoon whereas for South these are observed in the morning. From these results, the specific traffic observed during rush hour was computed by calculating the median values of cars per hour for both morning (7 am to 9 am) and afternoon (4 pm to 7 pm) periods (Figure 2-Figure 4).

Figure 1. Comparison between morning and afternoon traffic during rush hours for location L1. Barrier names and median traffic counting per hour for each direction are depicted in the pictures.



Source: own elaboration, 2025.

As mentioned, L1 is a large road with a lot of traffic with significant differences between morning and afternoon (Figure 2). In the morning, most vehicles are going south in both barriers. This tendency is partially inverted in the afternoon. For B1.2 there are more vehicles going North, whereas, for B1.1, this is not observed, but there is a decrease in the vehicles going South and an increase in the other direction. These observations confirm that we captured the effect of the rush hour, and that this is an area with high traffic volumes that are maintained beyond 7 pm.

Figure 2. Comparison between morning and afternoon traffic during rush hours for location L2. Barrier names and median traffic counting per hour for each direction are depicted in the pictures.

Source: Own elaboration, 2025.

L2 is also a location with high traffic volume, but adjacent to a residential area. For these reasons, the rush hour tendency (Figure 3) is similar to the observed for L1 (the trend is inverted between the morning and the afternoon). However, being already inside a residential area, B2.2 show much less traffic than the two others and the inversion is not evident in this case, hinting that mainly residents use this route. Interestingly, there is a very large difference between the counting going North on B2.3 and B2.1 (587 -> 316 in the morning and 998 -> 281 in the afternoon), indicating that most cars are turning West on this intersection. The same being true in the counting going South, which are much bigger for B2.3 than B2.1 suggesting that some of these cars may come from West.

Figure 3. Comparison between morning and afternoon traffic during rush hours for location L3. Barrier names and median traffic counting per hour for each direction are depicted in the pictures.

Source: Own elaboration, 2025.

The residential area (L3) also shows the same inversion related with the rush hours for most barriers (Figure 4). However, this effect is not so evident as in the first two locations probably for the same reasons mentioned above (heterogeneous type of intersections and camera angles). In these areas, particularly during rush hours, people tend to try different (and unexpected) routes to avoid traffic jams most likely taking different options in the morning and in the afternoon. Despite the higher complexity of this location, there are some observations that match the expected behaviour such as: B3.3 in the morning shows much more traffic going South (going away from the residential area), and B3.5 in the afternoon shows much more traffic going North (coming back from work).

7. Noise pollution during the night

According to the Environmental Noise Directive, environmental noise is described as unwanted or harmful sound derived from human activities, including noise emitted by means of transport — road traffic, rail traffic, air traffic, and from sites of industrial activity (Directive 2002/49/EC 2002). This directive points to road traffic noise as the predominant source of day-evening-night noise (Arregi et al., 2024). For locations L4 to L9, where devices were only powered during the night (in agreement with the public lighting schedules) the volume of traffic was compared (see Table 1) between three defined periods:

- Early night period: from 9 pm to 11 pm
- Night period: from 2 am to 4 am
- Early morning period: from 5 am to 6 am.

The number of cars follows the expected trend, of more cars being observed for the early night hours when compared to night and early morning periods. The values obtained for early morning periods are smaller than during the night, suggesting that larger traffic volumes start after 7 am.

The only location where this is not observed is L9, however the numbers are too small, and the difference is not significant (2 -> 5). The magnitude of the computed values is also as expected; locations L4 to L6 have more traffic volume since they are all close to entry points in the city. On the other hand, the numbers are much smaller for locations L7 to L9 since these are closer to residential areas. This allows us to infer that, inside residential areas, traffic generated noise pollution is not a concern, and residents are able to enjoy a peaceful and quiet night.

It is worth noting that, for L7, the poor lighting conditions (old sodium-based luminaires) affect the results and may explain the very small numbers observed for this location).

Table 1. Median traffic counting per hour for locations L4-L9 for early night, night, and early morning.

Location	Early night	Night	Early morning
L4	436	48	15
L5	254	14	4
L6	178	11	3
L7	20	2	2
L8	6	4	2
L9	34	2	5

Source: Own elaboration, 2025.

8. Conclusion

In conclusion, this work presents a successful implementation of an AI-powered edge computing device for measuring traffic flow in key intersections based on vision sensors. The solution was tested in three municipalities, covering nine (9) intersections, and the results show that it is suitable for traffic monitoring. The data collected can be used as a source of information for future projects in the locations studied. The solution was able to capture the effect of rush hour traffic and provide valuable insights into traffic flow patterns. Additionally, the solution was able to retrieve meaningful data during both day and night, demonstrating its feasibility.

Overall, this project represents a step towards the development of a new paradigm of connected urban infrastructure for the implementation of smart city technologies.

9. Acknowledgements

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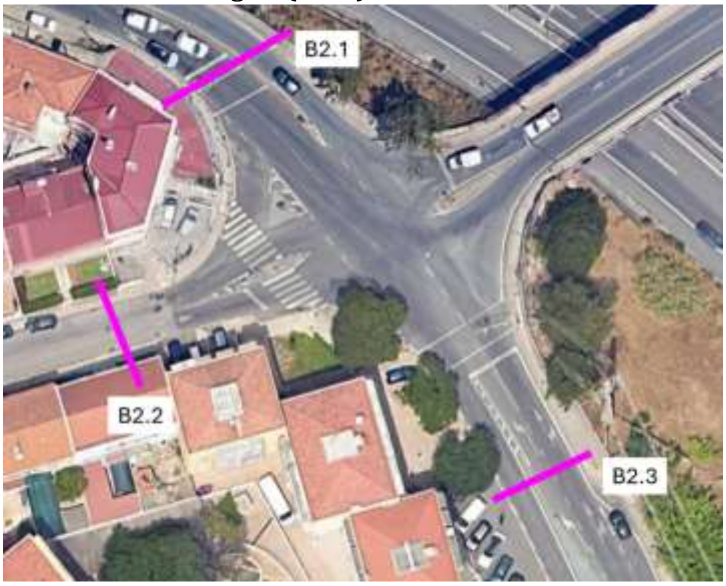
10. Supporting Information

10.1. Locations

Fig S1: Satellite (google maps) view of location L1. Magenta bars represent the places where the traffic flow was measured.

Source: Own elaboration, 2025.

Fig S1 (cont.): Location L2.



Source: Own elaboration, 2025.

Fig S1 (cont.): Location L3.

Source: Own elaboration, 2025.

Fig S1 (cont.): Location L4

Source: Own elaboration, 2025.

Fig S1 (cont.): Location L5.

Source: Own elaboration, 2025.

Fig S1 (cont.): Location L6.

Source: Own elaboration, 2025.

Fig S1 (cont.): Location L7.

Source: Own elaboration, 2025.

Fig S1 (cont.): Location L8.

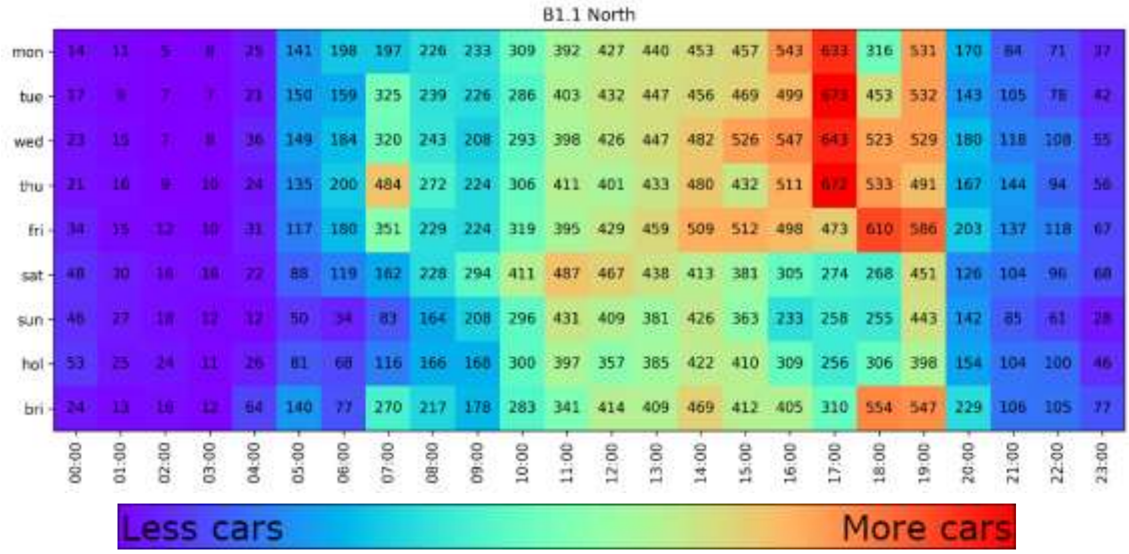
Source: Own elaboration, 2025.

Fig S1 (cont.): Location L9.

Source: Own elaboration, 2025.

10.2. Traffic Charts Per Barrier

Figure S2: Colour code representation of median values of traffic per hour for all weekdays ("hol" stands for national holidays and "bri" for days between holidays and weekends). Colour code goes from blue (less cars) to green and red (more cars). The colour scale changes for each location (since the counting change as well). Barrier code and direction are indicated in the title.



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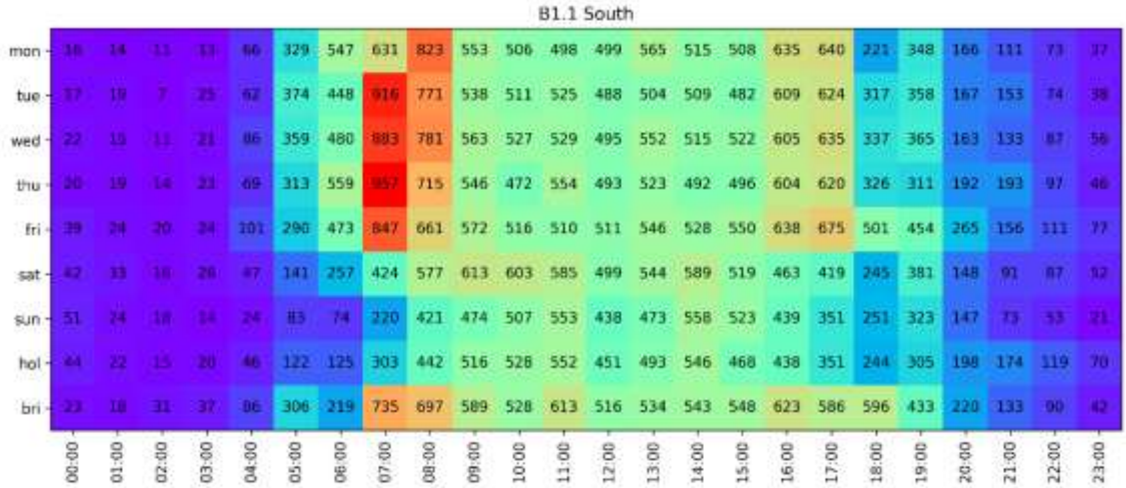

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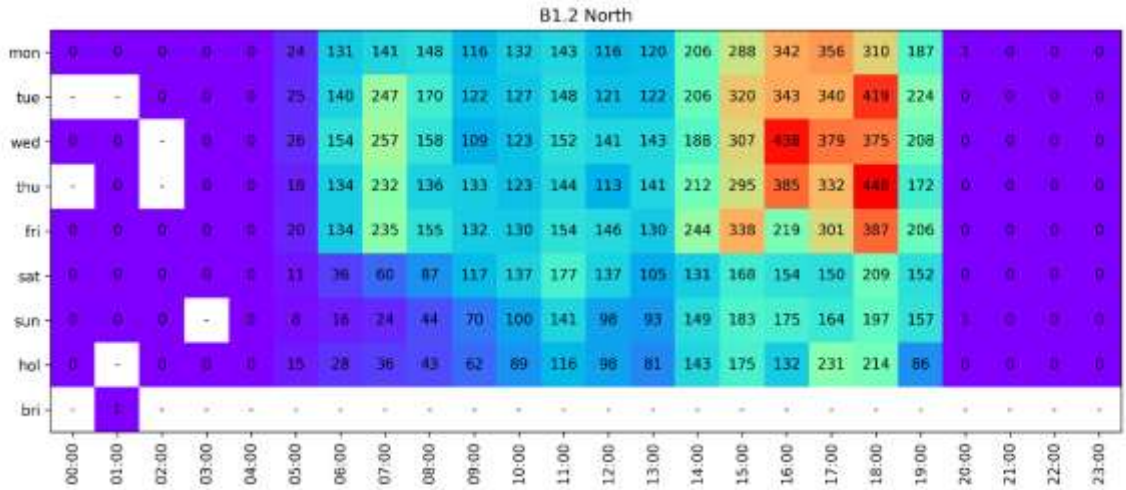

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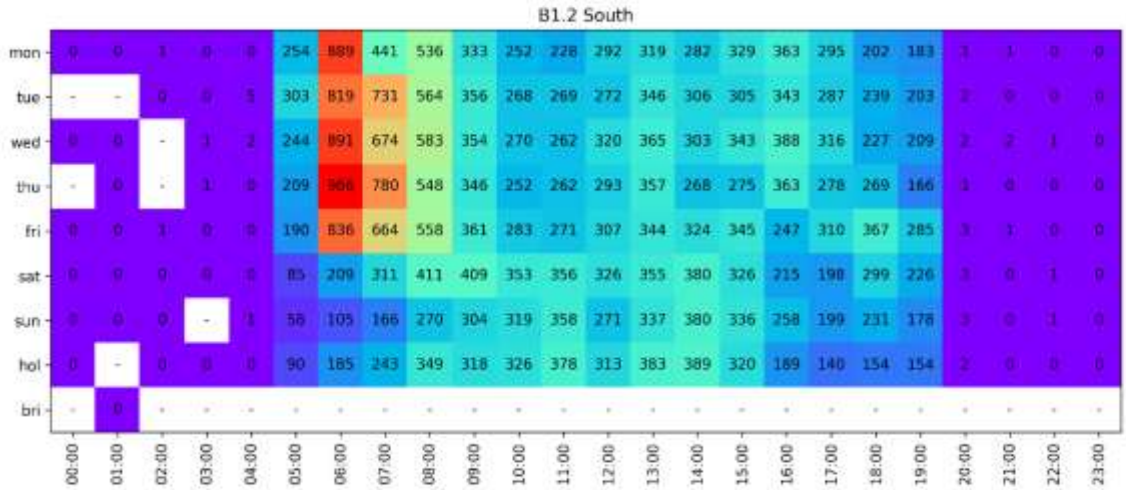

Source: Own elaboration, 2025.

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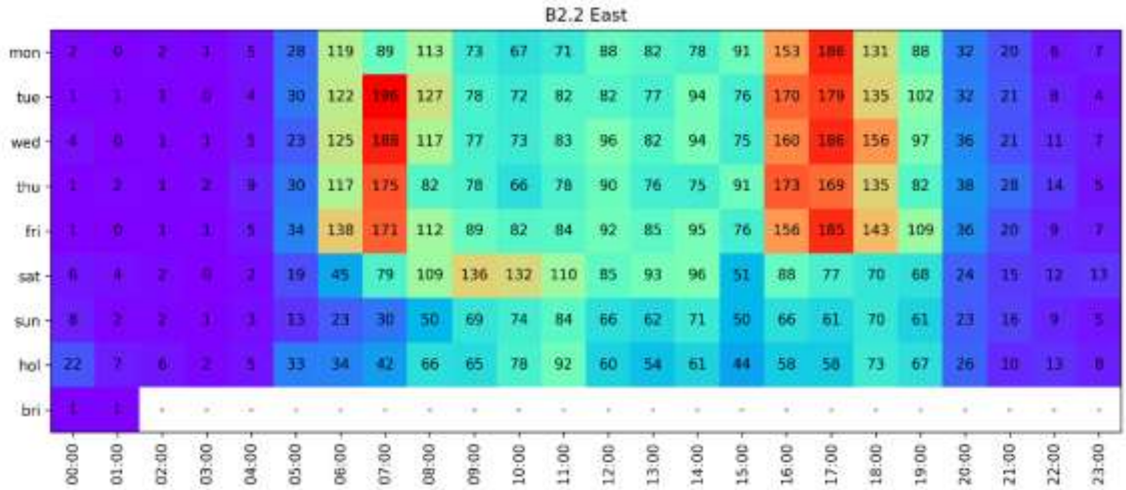

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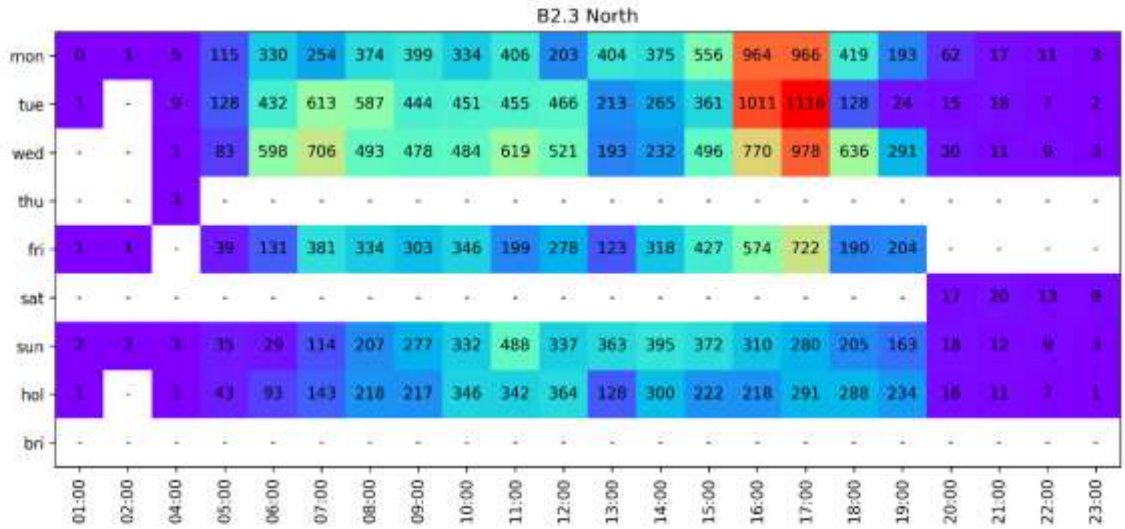

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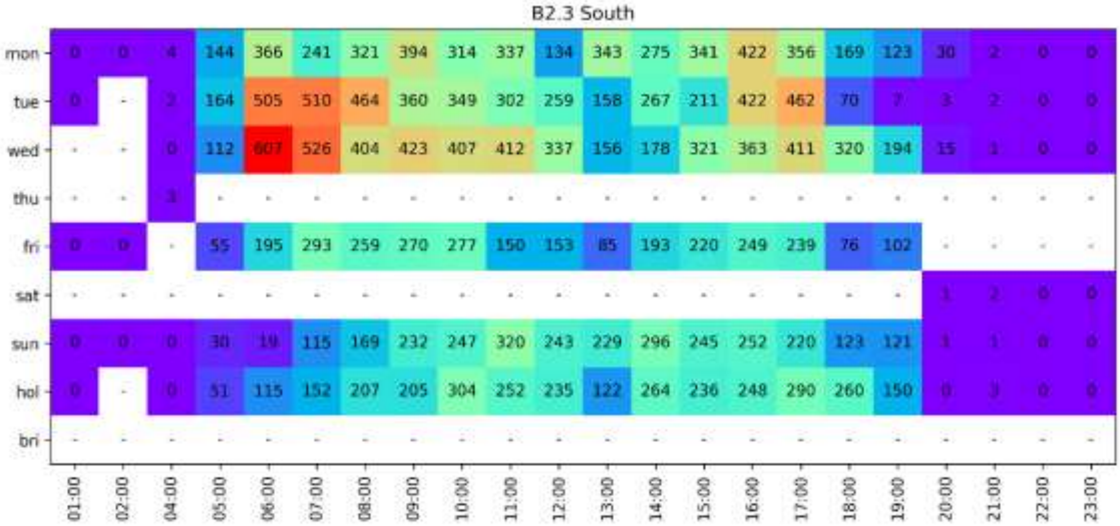

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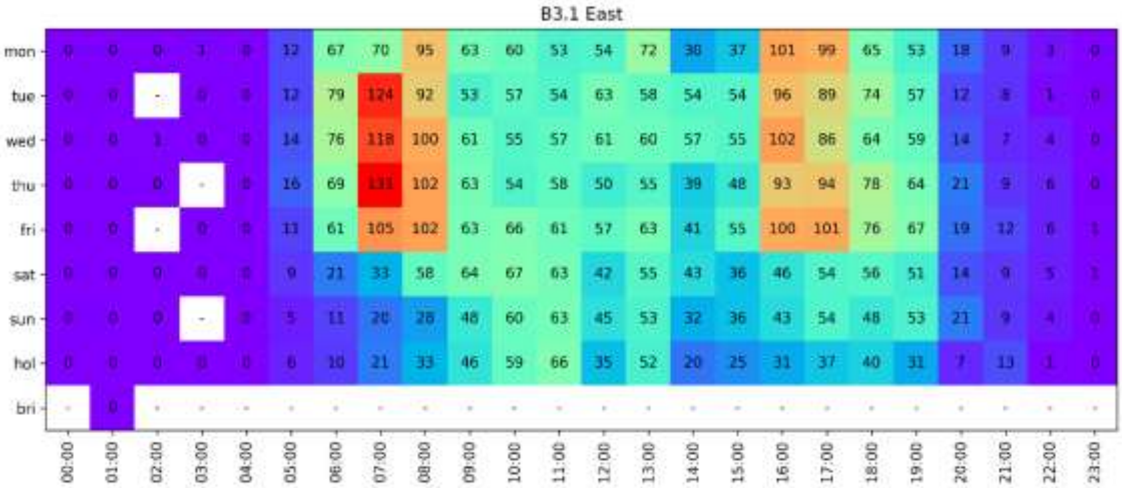

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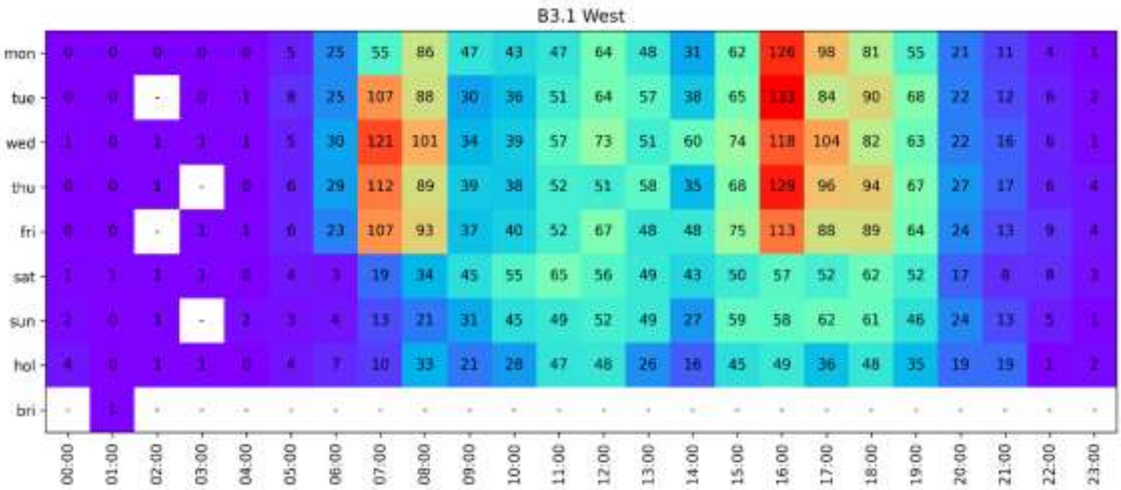

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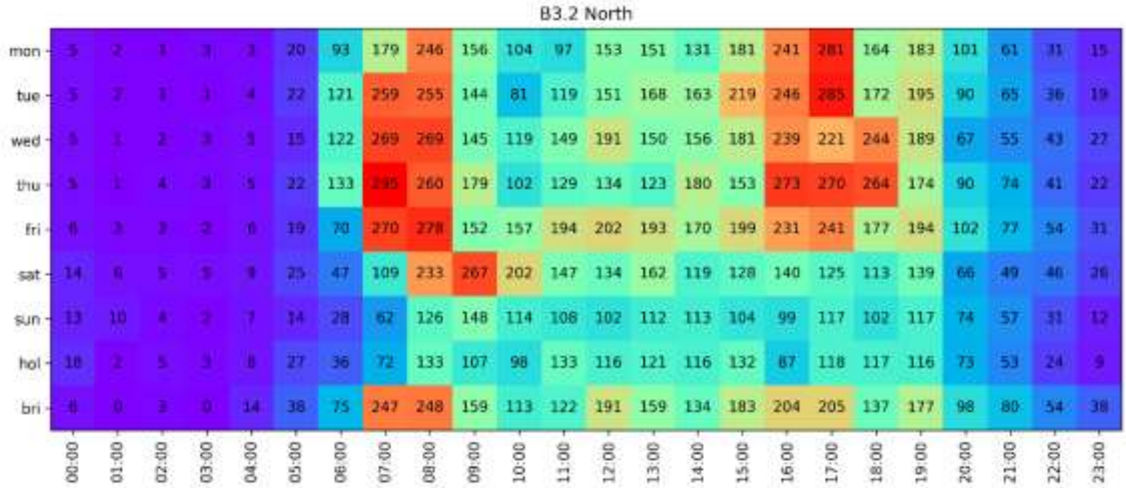

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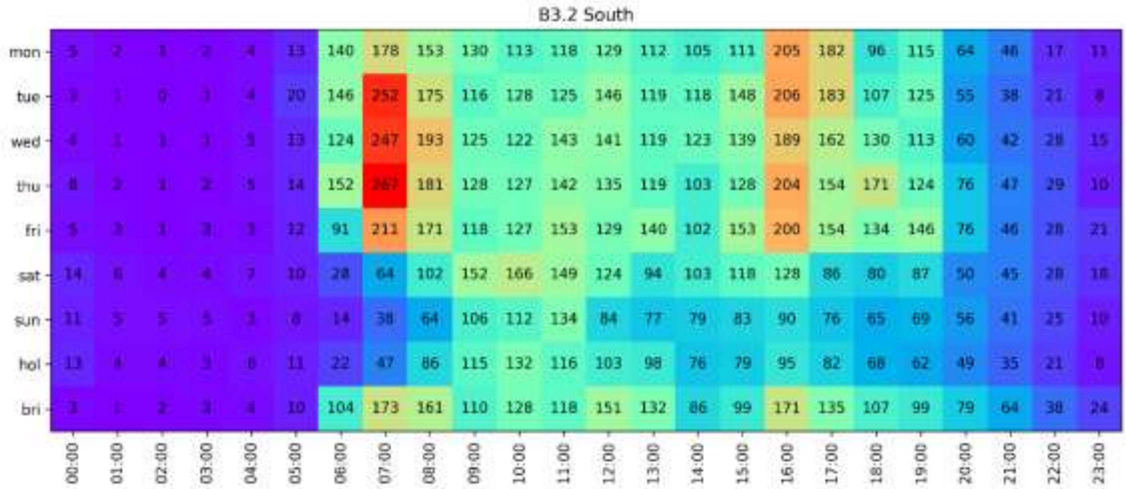

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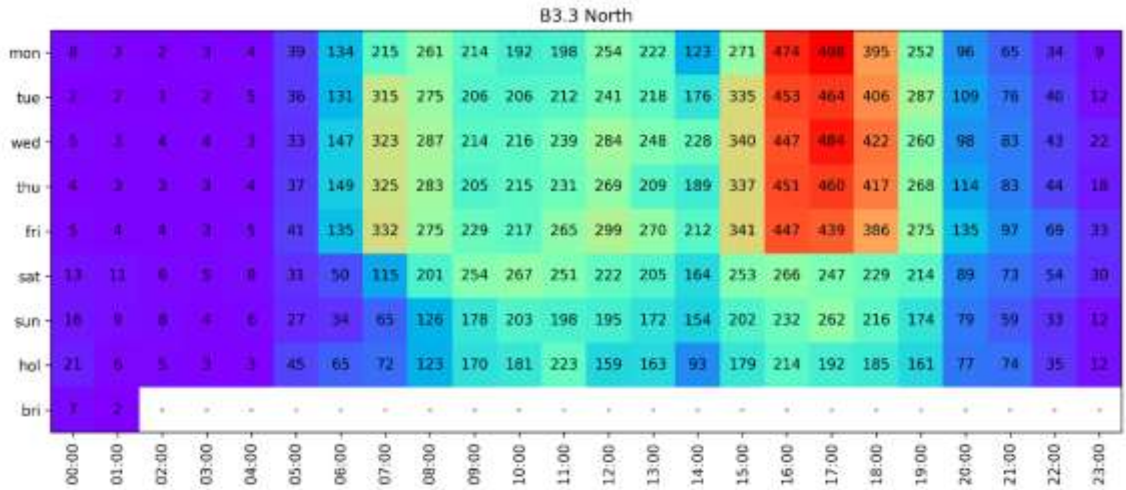

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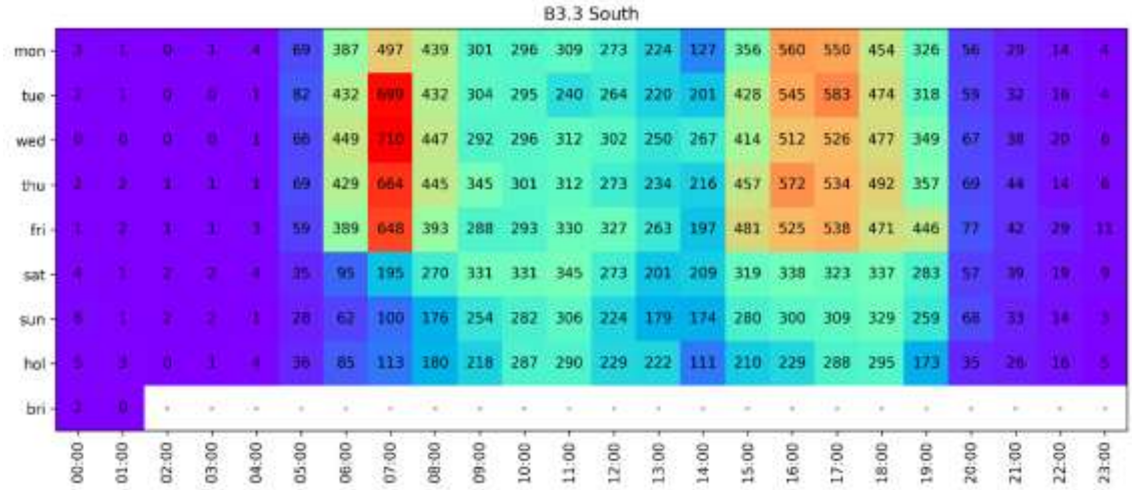

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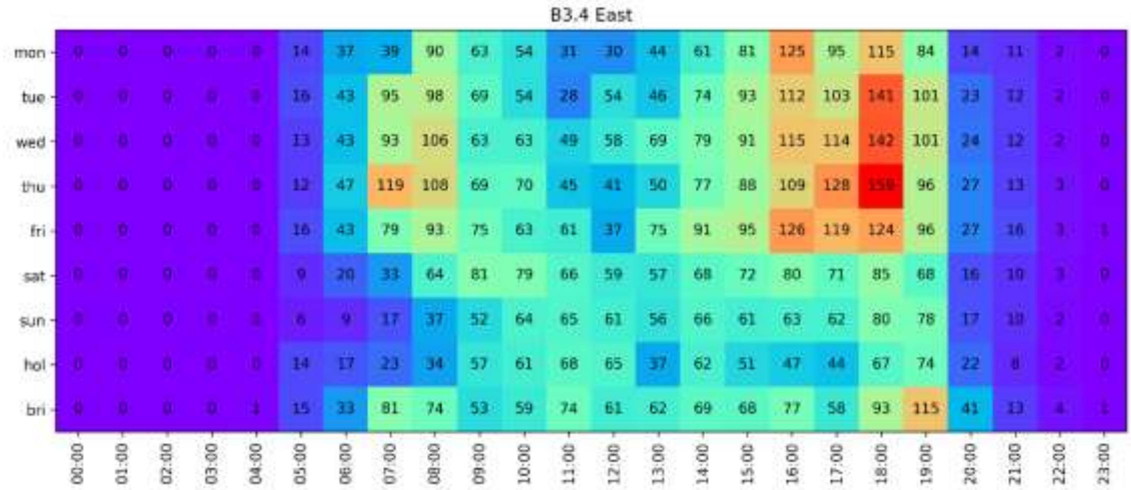

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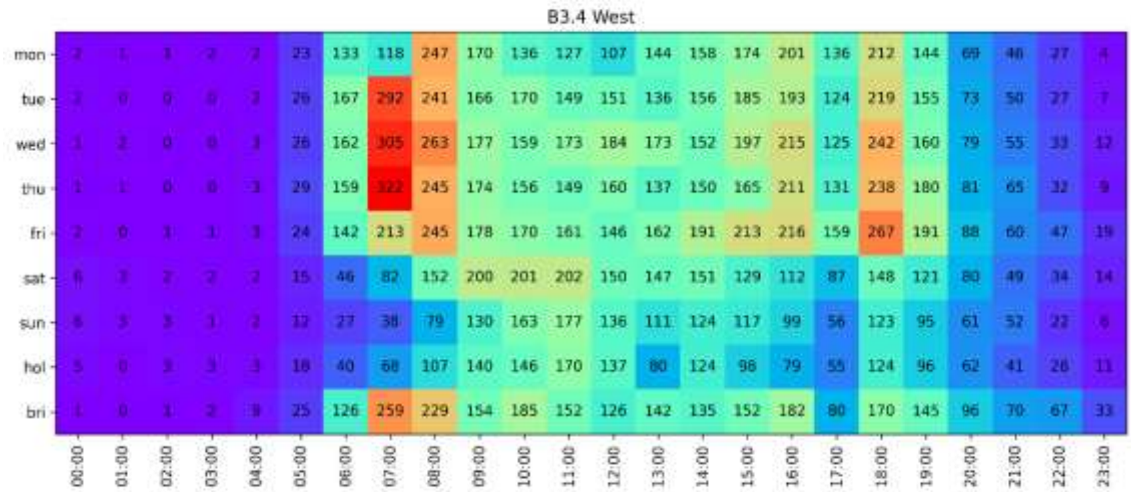

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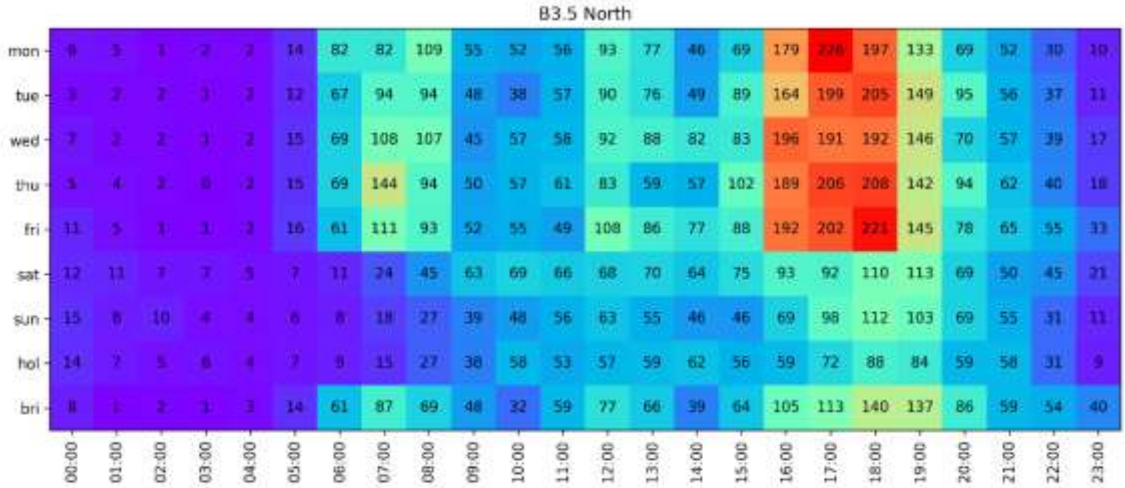

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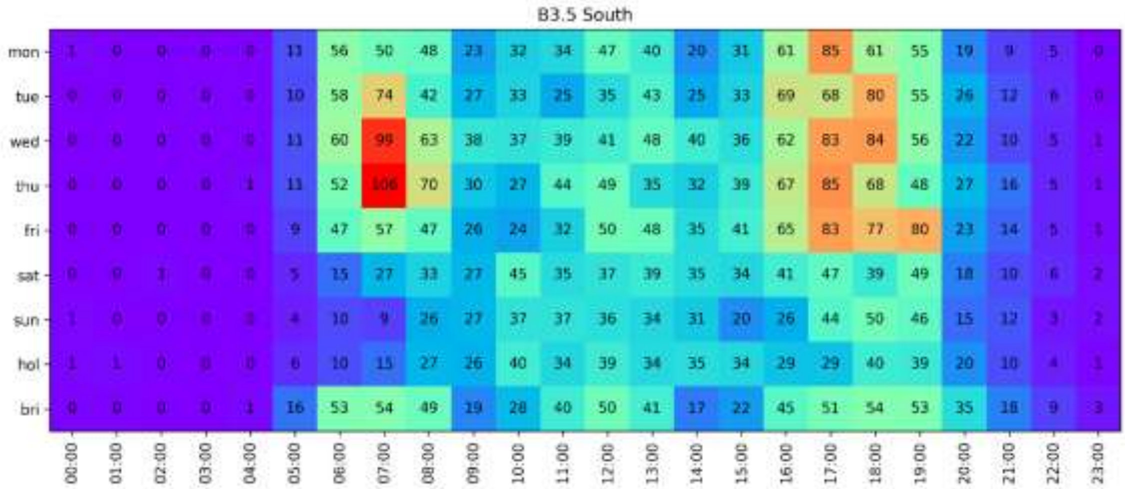

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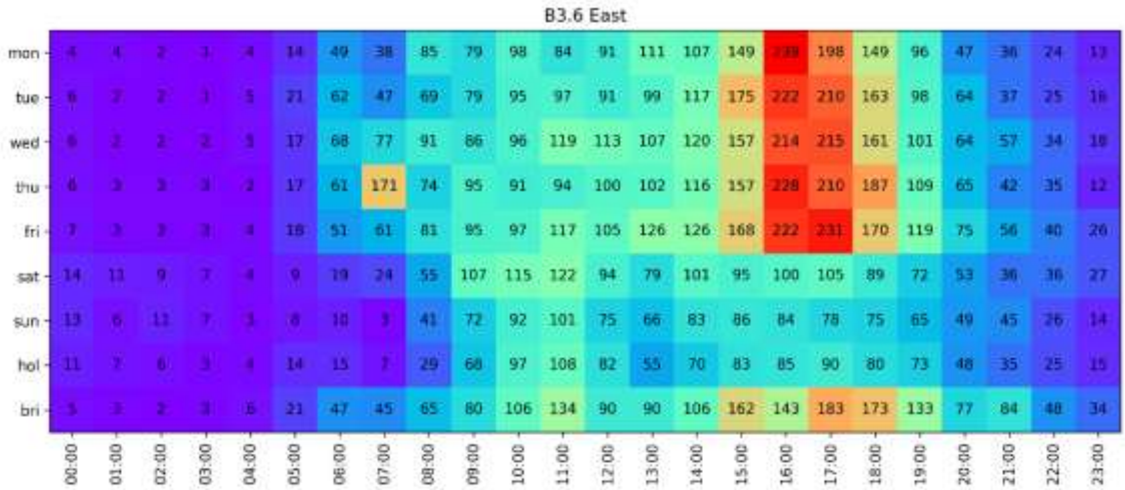

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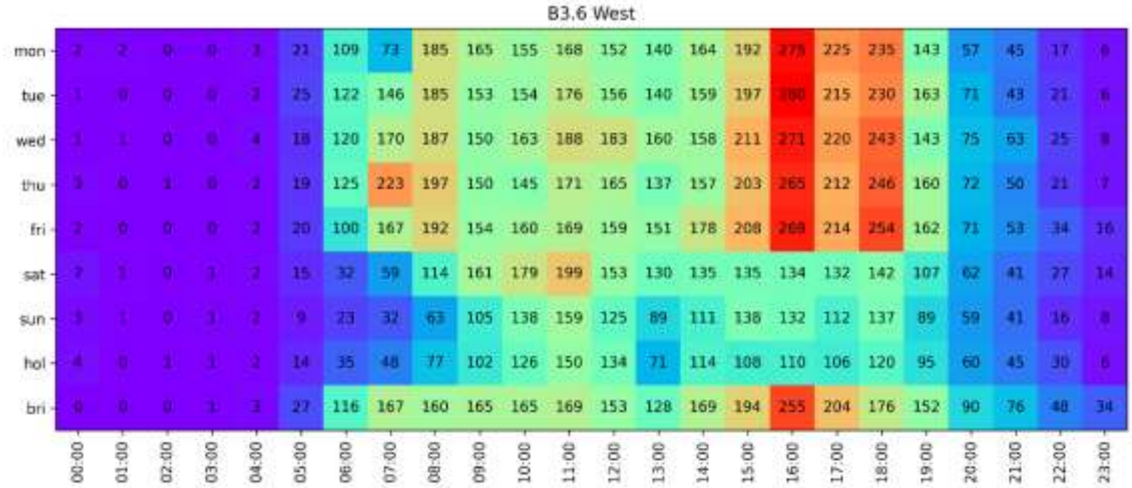

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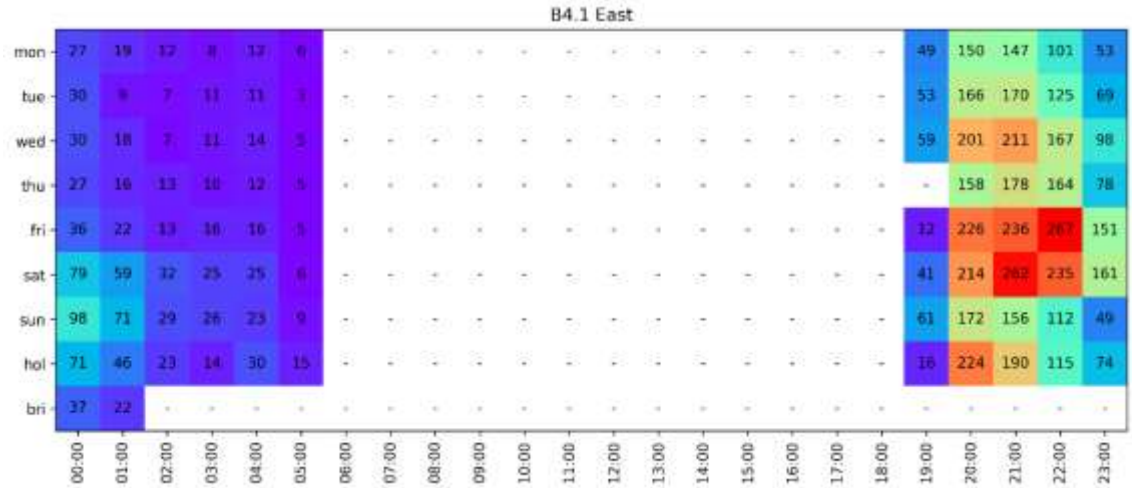

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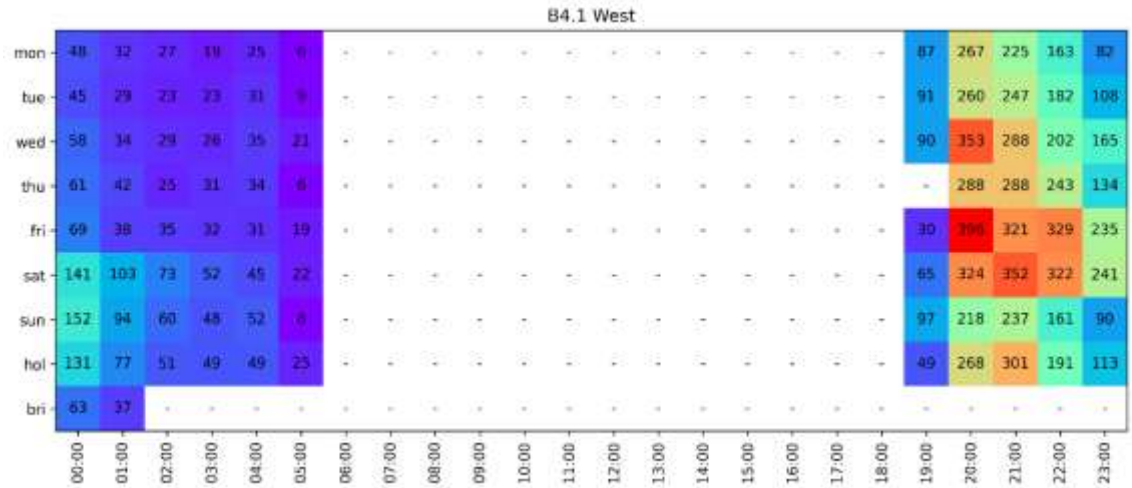

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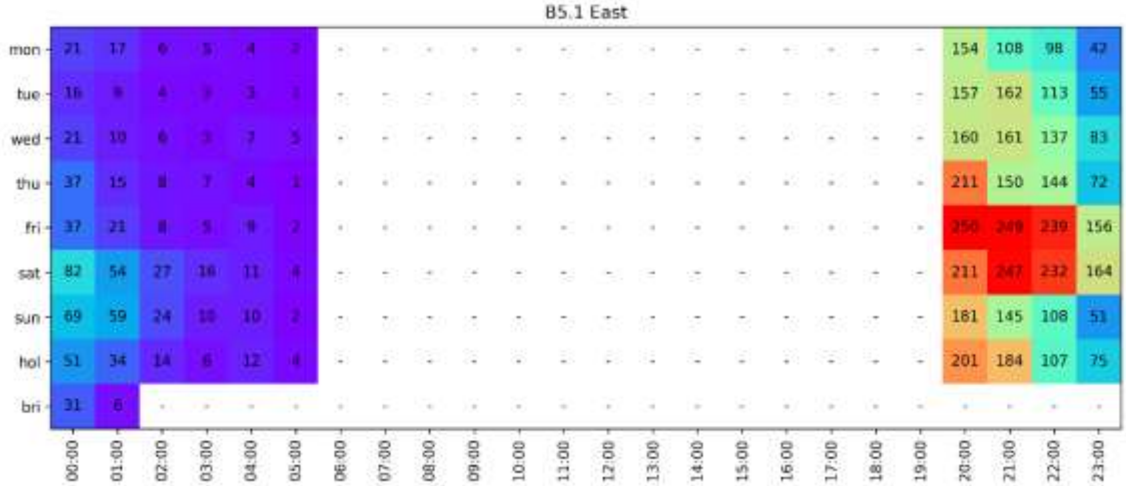

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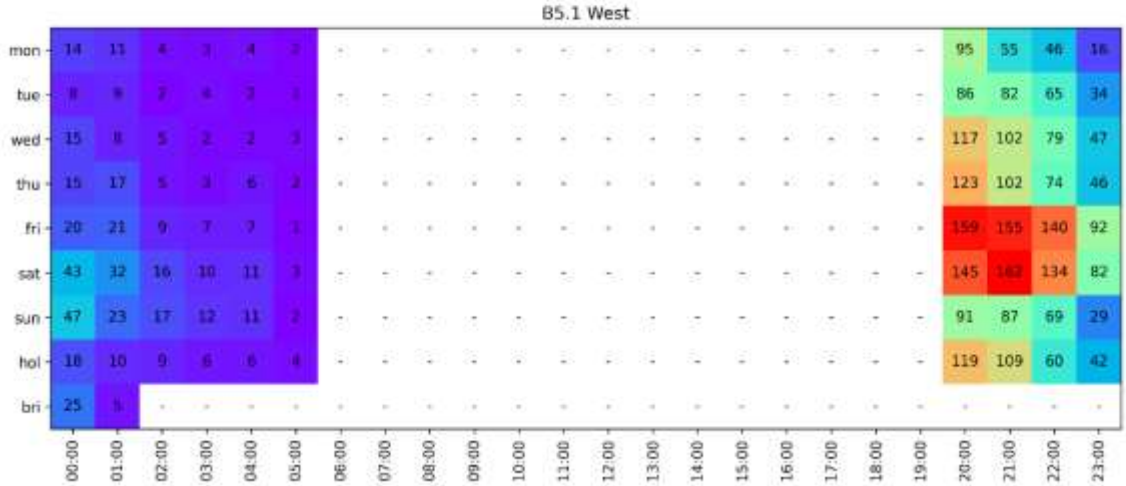

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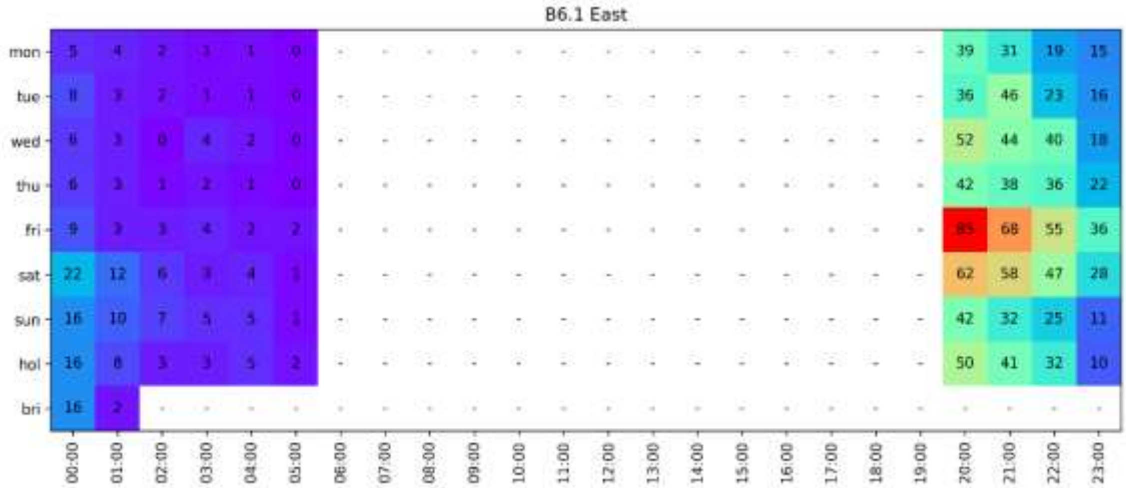

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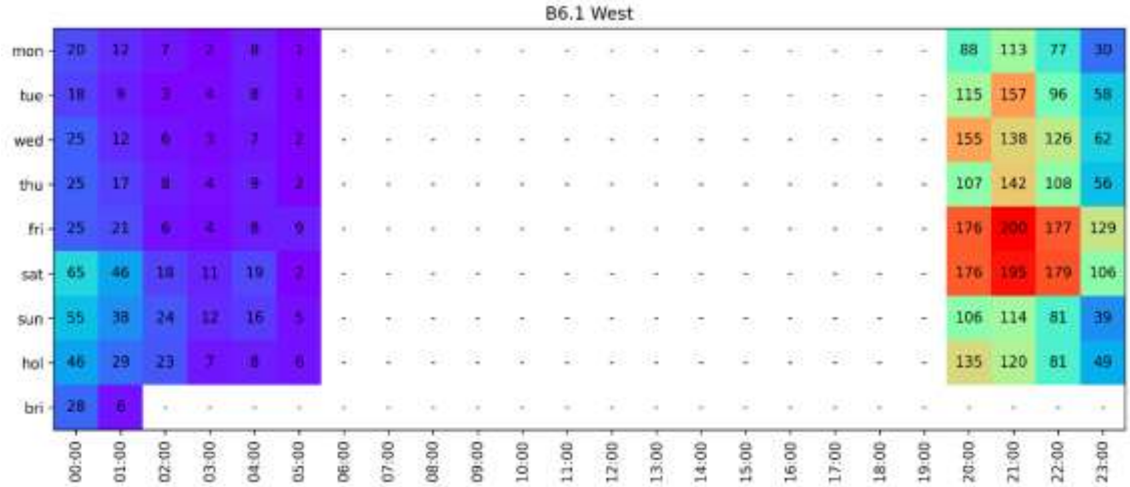

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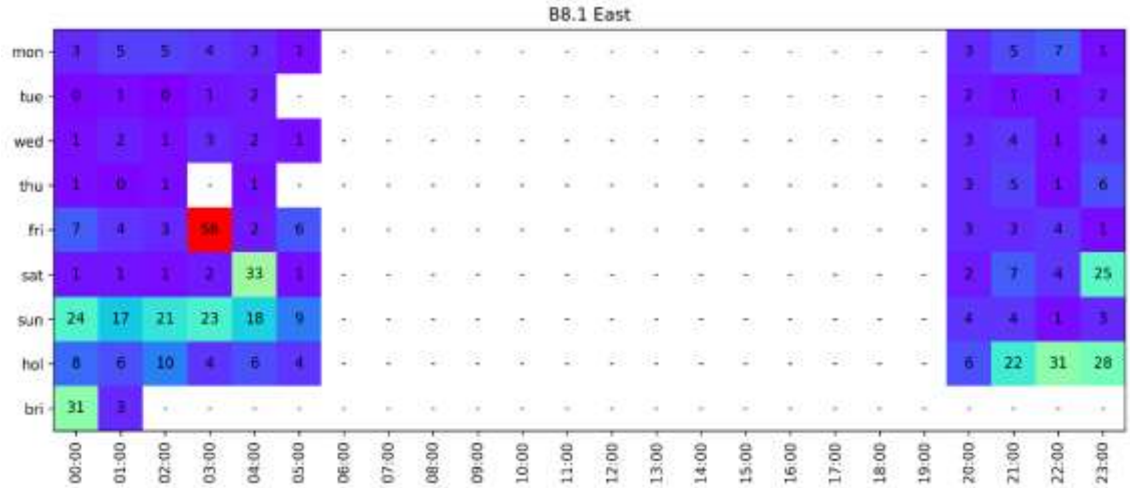
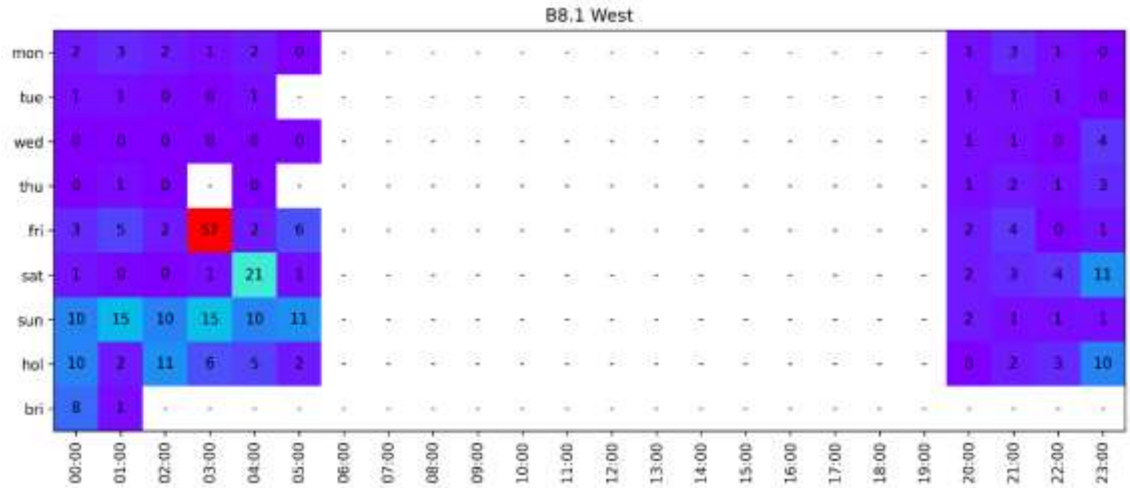


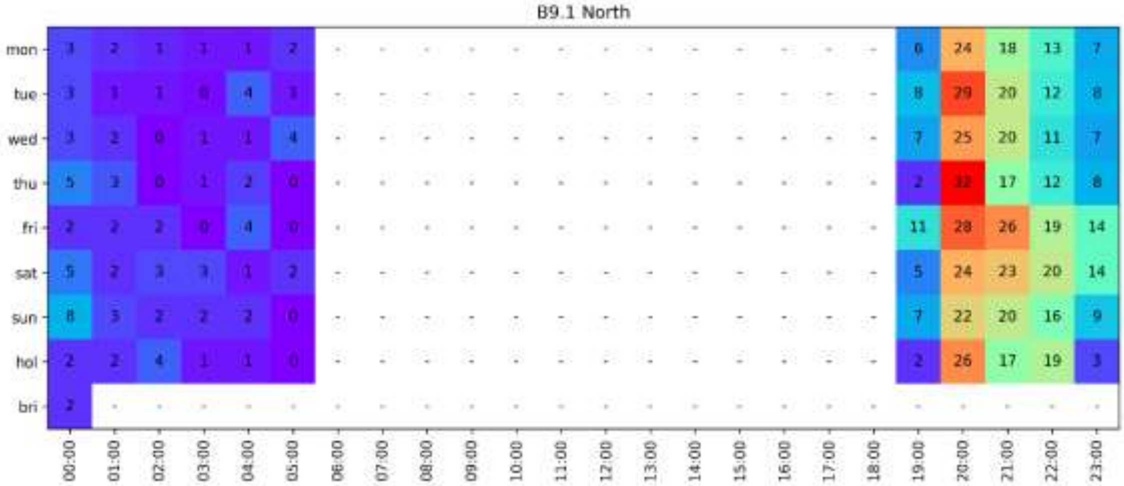
Source: Own elaboration, 2025.

Figure S2 (cont.).



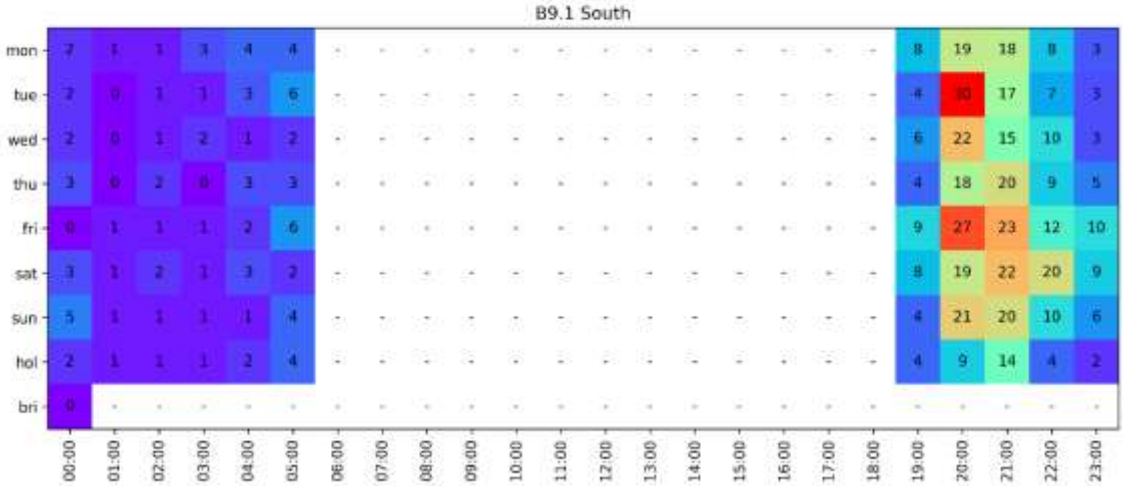
Source: Own elaboration, 2025.

Figure S2 (cont.).



Source: Own elaboration, 2025.

Figure S2 (cont.).



Source: Own elaboration, 2025.