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Investigating Transport Energy Consumption Patterns on Sustainable Campuses: A Study on Campus Residence at the University of Stavanger

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Sustainable mobility, sustainable campuses, annual transport energy estimation, living on campus, student housing planning, annual household energy consumption

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1. Abstract

This research investigates the energy consumption patterns of the students at the University of Stavanger, particularly that of the students residing in student housing facilities (SIS). An energy estimation methodology was developed and applied to analyse the annual consumption of students with a focus on transportation energy. Household energy consumption was also designated as a supplementary sector to achieve comparability with the results of the transport sector, revealing significantly higher yearly figures in households especially due to the cold Norwegian climate. Hereby, the study emphasizes the importance of transport energy which constitutes a substantial amount of a university student's energy footprint.

The study questions whether on-campus residency leads to lower energy consumption in transportation and carbon emissions, with a notion of promoting active transportation methods and enhanced campus amenities. It points out the potential of an expected shift to an electric bus fleet from the diesel equivalents and the energy reduction caused by the collective use of private vehicles. Furthermore, the research explores the relationship between housing density and energy consumption loads for transport and household sectors.

The findings demonstrate that densely built multi-dwelling housing facilities lead to lower household energy load per capita, but higher transport energy load per unit area, and the proximity to the campus results in lower annual transport energy consumption. Therefore, a combination of dense housing facilities and robust transportation strategies are the key factors to reduce energy demand. Although the results are context-specific to Norway, the research provides a replicable methodological approach for higher education campuses to reduce carbon emissions and energy consumption, while emphasizing the need for a holistic view of energy consumption, integrating individual behaviour, and comprehensive planning of sustainable transportation development.

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3. Introduction

3.1. Research Background

Urbanization and industrialization stand as the main accelerators in shaping the built environment in cities around the globe. While being a sign of human progress, this rapid development, unfortunately, brings significant drawbacks to our natural environment - the life source of planet Earth. The increasing urban sprawl and its accompanying energy consumption and carbon emissions have become a major concern, attracting the focus of numerous researchers and scientists. These experts put effort into investigating the environmental impacts of cities' rapid developments and identifying viable solutions to mitigate these harmful effects (Li & Lin, 2015).

Notably, close to 60% of the global population reside in small or medium cities according to the United Nations, however, the amount of research that is about these smaller urban areas has been disproportionately lower compared to the research focusing on larger cities and metropole areas (Lopez et al, 2019). The expansion of urban areas leads to a significant reduction of natural resources and an increase in human-caused greenhouse gas emissions such as CO2 and CH4. These emissions caused a 1.1°C increase in surface temperature over the 20th century, resulting in the warmest multi-century period in over 100,000 years (IPCC, 2022).

One of the key mitigation strategies involves transitioning away from fossil fuels and towards renewable energy sources. This transition, when brought together with robust policies regulating the use of fossil fuels, has shown promising results in reducing greenhouse gas emissions in several countries (IPCC, 2022). It emphasizes the urgent need for all stakeholders to support the development of a sustainable built environment with renewable energy sources. Architects and urban planners stand at the forefront of this effort. Their role is not only crucial in terms of practical urban development but also as advocates for a sustainable future. In both practice and academic research, architects and planners have the opportunity to implement sustainable solutions, investigate new technologies, and push for significant environmental advancements (Brundtland, 1987).

In the context of this broader global scenario, this research focuses on an impactful scale of urban development, which is the university campuses. Functioning as small cities within themselves, these campuses represent the potential for exploring energy efficiency and sustainable transport and offer practical solutions towards achieving a more sustainable urban future.

3.2. Sustainable Campuses

Alongside being educational centres, university campuses also function as a microcosm of urban ecosystems with residential, operational, and transportation features. Their relatively smaller scale makes them ideal test beds for studying and implementing sustainability practices, as a representative of the city scale. (Villegas-Ch et al, 2019) Sustainable campuses are becoming an important area of academic research and practical action aiming to achieve environmental sustainability. These campuses act as living laboratories for testing sustainability strategies and provide valuable insights into the wider urban context. The concept of a sustainable campus includes several aspects such as energy efficiency, sustainable transportation, green building practices, and harbouring a culture of sustainability among its users. (Sonetti et al, 2015)

A sustainable campus is characterized by its efficient use of resources, minimizing waste, and reducing carbon emissions. It aims to reduce its environmental impact by integrating renewable energy sources and prioritizing energy-efficient buildings and infrastructure for a sustainable transport network. A sustainable campus should promote a shift towards soft transport modes such as walking, cycling, or public transport while reducing the reliance on private cars that highly contribute to global carbon emissions. Campuses should also include study and research programs dedicated to sustainable strategies on the built environment and their implications on the field to emphasize the significance of academic investigation regarding Sustainable Development Goals.

This study conducts research within the context of sustainable campuses. It focuses on the relationship between the campus residency of university students and their transport energy consumption by investigating various factors such as travel behaviour, distance to campus, and bus occupancy. The study follows the ultimate aim of contributing to the ongoing effort of creating more sustainable university campuses.

3.3. Sustainable Mobility

Transportation planning plays a significant role in the shift towards a sustainable built environment. Providing access to safe, affordable, accessible, and sustainable transport systems is included as a significant objective in the UN's Sustainable Development Goals under the 11th goal Sustainable Cities and Communities. (UN General Assembly, 2015) Sustainable mobility, as an optimization of transport systems, carries the potential to make a substantial change in global emissions and energy consumption. This objective can be achieved by integrating technological developments and renewable energy sources to enhance the energy quality of local transportation infrastructure. Ambitious plans and strategies developed by planners which aim towards this goal can lead to remarkable results.

The concept of Sustainable Urban Mobility Development calls for a people-focused, accessible, environmentally safe, and economically viable transport system whit an emphasis on the inclusivity of all transport modes and valuing the active participation of citizens (Consult, 2019). A well-planned and integrated transport system that offers convenient and inexpensive public transport options, balanced with private vehicles and soft transport modes, is a crucial factor in reducing car dependency (Buehler et al, 2016).

However, one of the most considerable challenges in achieving this vision is encouraging people to choose public or active modes of transport. The users are likely to depend on their private vehicles if the public transportation network is not functioning well in terms of safety, punctuality, travel time, comfort, and cleanliness (Lierop et al, 2018). Thus, if a successful transport network is achieved, more people can be persuaded to prefer sustainable transport modes in their daily commuting. Consequently, the technological and strategic developments aiming for energy efficiency in transport planning can become effective in coping with negative outcomes of consumed transport energy.

Within the context of sustainable campuses, understanding sustainable mobility's significance is crucial to have impactful mitigation strategies and it enhances the campus's overall energy performance. This research investigates the key aspects related to sustainable transport on university campuses, to offer insights into sustainable mobility strategies in a campus environment.

3.4. Research Question and Objectives

Considering the objective of a sustainable campus, energy consumption is often classified into different sections to analyse different areas and their contribution to the overall energy performance or carbon footprint. Major energy sectors that are investigated are building operation energy, transport energy, waste disposal energy, outdoor space operation energy etc. These sectors can be further broken down for more in-depth analysis. Such an approach sheds light on a part of the complex structure of a campus' energy performance and provides useful information for policymakers and planners in their decision-making process.

This study focuses on transportation as one of the key energy sectors in achieving a sustainable campus setting. The main objective is to investigate the transport energy consumption resulting from daily commuting at the campus of the University of Stavanger. More specifically, this research aims to answer one essential question and several supplementary questions as follows:

- Does residing on-campus reduce the transport energy consumption of inhabitants of the student housing facilities in Stavanger when compared to the students residing off-campus?

    - What are the proportions of transport energy consumption when compared to another sector?
    - What are the key factors influencing the overall transport energy consumption?

The proximity of living on campus negates the need for a home-to-university commute for many students, however, it is recognized that the students have other regular routes on a weekly basis including trips to the city centre for leisure activities, study purposes, and part-time jobs outside the university hours. Considering these aspects, the study investigates the annual consumption of transport energy for the inhabitants of student housing facilities in Stavanger based on their residence location and weekly travel behaviour to the campus and the city centre. Therefore, the findings can provide beneficial insight for stakeholders taking part in the planning process of student housing facilities and university campus transportation.

The main objectives of the research are as follows:

1. Estimating the annual transport energy consumption of the students dwelling in student housing facilities.
2. Estimating the annual household energy consumption of student housing facilities.
3. Making a comparative analysis of the transport energy load of on-campus and off-campus students.
4. Examining the proportions of transport energy to household energy.

By using the results from the estimations, the study aims to discuss the energy consumption patterns related to the residence location proximity to the campus for the transport sector and the proportion of the transport energy consumption to the household energy sector, while examining the key factors affecting the energy loads in a university campus.

4. Literature Review

This section presents selected academic papers from the literature on sustainable campuses and sustainable mobility with their relevance to the mentioned topics and this study itself. The synthesized information gathered from the chosen research papers is aligned according to their proximity to the subjects. The subtopics are sequenced as follows: sustainable campuses (1), sustainable transportation at the campus (2), travel behaviour studies (3), and transport energy estimation (4).

4.1. Sustainable Campuses

University campuses as small-scale districts harbour a dynamic complexity within their living environment. Their educational, residential, and commercial facilities with high-volume transport systems make the campus area vibrant. This complex form of living environment carries numerous aspects of the larger city scale. Therefore, especially in sustainable development research, investigating the energy performance of university campuses helps to comprehend more complex settlements such as small-scale cities or metropole areas.

Amaral et al. aim to define the key areas influencing the environmental performance of higher education institutions in achieving a sustainable campus environment. The findings demonstrate that developing countries tend to invest more in sustainable practices and the universities' tendency to integrate sustainability in their educational and research programs is dependent on governmental support. They also argue that instead of implementing individual actions, integrating sustainable strategies within the cultural environment both on the campus scale and globally leads to more impactful solutions. (Amaral et al., 2020) Alshuwaikat and Abubakar also suggest a holistic and systematic approach to treating sustainable issues within the universities rather than specific project-based applications. The authors emphasize the significance of incorporating sustainable ambitions in education and research activities on the subject matter through a more integrated approach that promotes sustainable development on a global scale. (Alshuwaikat & Abubakar, 2008)

The pivotal role of university campuses is also emphasized by Finley and Massey in their research that points out the significance of higher education campuses in addressing sustainability-related issues through research, education, and innovation. The study evaluates the integration of the concept of eco-city, brought up by Richard Register, into higher education campuses. The authors argue that the eco-campus model can be used as an impactful tool to achieve progressive results in sustainable campuses by realigning institutional practices. Thus, university campuses can improve their global standings with ambitious sustainable actions and become transformative districts for social change. (Finley & Massey, 2011)

Ridhosari and Rahman emphasize the significance of promoting environmental awareness on university campuses by reducing carbon footprint in their practical study. The research aims to assess total carbon emission at the University of Pertamina, investigating three sectors: transportation, building electricity usage, and waste generation. (Ridhosari & Rahman, 2020) On the other hand, Sonetti et al. investigate how to assess the criteria for a sustainable campus under the Campus Sustainability Assessment framework and make a comparison between two different campuses in Italy. The study analyses the morphological structure of university campuses within the city focusing on transportation as a major sector contributing to carbon emissions of the campus. (Sonetti et al., 2015)

4.2. Sustainable Transportation on Campuses

Investigating transportation systems within urban areas is a significant effort to reduce carbon emissions resulting from the massive amount of fuel used on a daily basis. Developing policies and regulations aiming for a sustainable transport network stands out as an impactful action. However, it is yet another complex process to design and improve a well-functioning system regarding the social, economic, and environmental aspects. Awasthi et al. evaluates the decision-making process in the pursuit of sustainable urban transport systems to overcome uncertainties with a multi-criteria approach. The authors define the criteria, collect linguistic data from a selected cluster of experts on multi-criteria evaluation, and use a method to analyse the alternatives and influence of each criterion on the decision-making process. They eventually aim to illuminate the complex process of developing sustainable transport systems. (Awasthi et al., 2011)

Qureshi and Lu also argue that a holistic approach to the policies, applied projects, and infrastructure can give practical insight into the complexity of sustainable transport development. The study analyses the sustainability of the public transport system in Karachi, Pakistan by evaluating the transport and infrastructure systems, environmental transport policies, and transport projects. (Qureshi & Lu, 2007) The vast complexity of transport systems in urban settings can be stated as a major challenge that requires huge timewise and economic investments to study and understand the broad gaps and possibilities. In addition, each transportation network of a different urban setting includes context-specific factors that carry the complexity level to another dimension. For these reasons, university campuses are feasible scales to investigate transport systems as seen from various academic works in the literature.

Lopez et al. focus on the challenges in presenting transport strategies that aim for a green and walkable campus while managing economic constraints regarding the transportation infrastructure in higher education institutions. The study investigates the use of Transport Demand Management with a case study at the University of Florida, which is an ambitious strategy for promoting soft transport modes within the campus and includes the participation of local transport companies. Their findings show the mutual benefits of the system for the university and the company in terms of achieving a sustainable campus while arguing that more emphasis is needed on transit improvements, parking regulations and parking pricing due to the high level of car dependency. (Lopez et al., 2019)

University campuses are among the significant contributors to global transport energy consumption because of the high usage of private motorised modes. (Sukor & Hassan, 2017) The dependence on private vehicles on university campuses is also discussed by Dehghanmongabadi and Hoşkara in their study in 2018. Their research aims to outline the benefits of sustainable mobility and identify strategies to promote active transportation on university campuses. It emphasises the higher education institutions’ potential of spreading awareness about the impact of sustainable transportation. (Dehghanmongabadi & Hoşkara, 2018)

Besides the effort to reduce car dependency, improving the quality of the public transport network as well as the infrastructure of walking and cycling is crucial in university settings. Sonetti et al. argues that a dedicated transport system is a major performance criterion in terms of the ability to limit private vehicle usage and promote public transport, the availability of the bus network within the campus, and the practicality of bicycle usage. (Sonetti et al., 2015) Filippo suggests an energy model that is used to assess the feasibility of a bus network with different fuel types within a different setting. The study examines the feasibility of a shift from fossil fuels to electricity in the fuel type of public transport bus fleet around Ohio State University within a context called Campus Area Bus Service by developing an energy model considering the charging stations and charging policy for buses. (Filippo, 2014)

4.3. Travel Behaviour Studies

In order to understand the performance of a transport system at a university campus, the travel patterns of the users need to be considered since the network must be designed regarding the behaviour of the people who utilize the transport system. Travel behaviour surveys within university campuses are used by researchers to promote sustainable transport on campus. For example, Hamad et al. conduct a well-designed survey for all users of Skyline University College in the United Arab Emirates to understand their travel behaviours. The survey includes highly detailed queries about demographics, trip characteristics, car ownership, and attitudinal preferences in order to identify the travel patterns of users. They aim to provide solutions to deal with issues in the transport system. Thus, the authors generate recommendations on how to promote sustainable transport in a university setting based on these patterns focusing on public transport and active mobility. (Hamad et al., 2021)

Limanond et al. conduct a behaviour analysis of the students residing in rural universities in Asia by investigating the distinct travel patterns related to gender and car ownership. The findings demonstrate that rural universities lack a robust transportation system and surrounding attraction areas when compared to urban universities. Therefore, students in rural universities often tend to travel to off-campus locations for leisure activities mainly via private vehicles. It consequently underlines the significance of reducing car dependency and promoting public transport modes to achieve a sustainable campus environment. (Limanond et al., 2011) Also focusing on the increasing number of motorized vehicle usage within a university campus, Norwalzi and Ismail present an approach to deal with the detrimental effects of car dependency with a focus on sustainable mobility, that benefits from various methods. They use questionnaires and interviews to analyse the transportation behaviour of students and develop strategies to mitigate the issue. (Norwalzi & Ismail, 2011)

Prillwitz & Bar suggest a segmentation approach towards individual mobility attitude characteristics of people in order to promote sustainable mobility effectively. The study investigates the individual attitude of people in the decision process of using different transport modes and presents an approach that benefits from a travel behaviour survey to provide a segmentation analysis of the users' attitudes towards soft transport modes. The results show that regardless of socio-demographic and economic aspects, the travel behaviour of the participants differs from each other in terms of their ambition in using sustainable transportation. (Prillwitz & Bar, 2011)

4.4. Transport Energy Estimation

Al-Ogaili et al. argue that there exist several studies on the energy estimation of electric buses, however, the detailed classification of applied methods is limited. Therefore, they aim to review existing energy estimation strategies within their paper. They emphasize the significance of knowing the figures for the energy use of the bus fleet in urban areas in order to plan expansions or strategic electrification within the bus network. (Al-Ogaili et al., 2021)

The importance of classifying the energy estimation methods is also stated by other authors. Ma et al. classifies the methods into two main groups: fuel-based and vehicle activity-based estimations. The former is stated to result in rough estimations utilizing the fuel economy data and defined as energy consumption per unit distance, whereas the latter uses historic data on bus activity which can lead to fine-grain estimations considering various detailed factors such as bus operation characteristics, road elevation, and ridership effects. The study suggests a data-driven estimation model for the energy consumption of diesel and electric buses by using GPS data. It investigates the differences between the two fuel types in terms of consumption reduction rates at speed, route, and traffic congestion. It consequently gives recommendations on the decision process of electrification of the bus network in specific routes. (Ma et al., 2021)

Gallet et al. point out the lack of existing high-detail and large-scale energy demand data on public transport networks. They propose a methodology that focuses on real-world bus route characteristics to estimate the energy demand of the bus fleet. The study values realistic and accurate route-specific estimates over focusing on coarse average estimation figures. The authors also mention the simplicity and practicality of average estimations proportional to travel distance and the wide use of this method within the literature while noting that the traffic conditions are neglected in this approach. (Gallet et al., 2018)

On the other hand, Sukor and Hassan embrace the fuel-based approach in their research aiming to estimate the average energy load of public transport buses. They state that identifying transport energy consumption is one of the first steps to achieving a sustainable campus. The study conducts a comprehensive travel behaviour survey in the Engineering Campus of Malaysia Science University targeting university staff and students to determine the parameters needed for the transport energy calculations such as travel distance, travel speed, and number of trips per day. (Sukor & Hassan, 2017) Paul and Yamada propose an algorithm that utilizes the travel distance of public transport buses and the bus schedule dataset to calculate the total distance travelled by the bus fleet. The study also analyses the differentiation between electric and diesel buses and their routes in the bus schedule. (Paul & Yamada, 2014)

Wang et al. focus on the operational cost differences between diesel and electric public transport buses. The study analyses the charging systems and locations of electric buses while comparing the cost-effectiveness and efficiency of operation to the diesel bus fleet. Their findings demonstrate that the electric bus fleet is not only environmentally friendly but also cost-efficient in terms of operating expenses. (Wang et al., 2017) In the study of Ridhosari and Rahman, a series of rough annual emission estimations are made to perform a comparative analysis between the energy loads of three sectors in a university campus:

transportation, building electricity, and waste production. In the method, the distance and the amount of fuel needed for the trip are calculated for different modes of transport. The findings present a clear hierarchical classification between the sectors' contribution to emissions, with electricity usage leading the other two sectors. (Ridhosari & Rahman, 2020)

In conclusion, the literature review presents an overview of the significant role of university campuses in studies related to sustainable development. It is noted that higher education campuses function as microcosms representing the larger urban scale and their complexity requires a holistic approach to be able to understand and mitigate the issues related to sustainability. It is also emphasised that integrating sustainable policies and practices into education, and research activities within university campuses is essential.

Furthermore, university campuses as major contributors to transport energy consumption within the urban ecosystem are often taken into consideration together with the concept of sustainable mobility in the literature. The findings from the literature reveal three major considerations. A comprehensive approach to transport planning, a robust transport network design, and promoting a change in people's transport behaviour have a huge role in achieving a sustainable transport system. It is also emphasized that travel behaviour surveying provides valuable insight into the travel patterns of users of the transport network in research, which leads to a better understanding of the characteristics of travel choices.

Finally, the selected studies from the literature present a consensus on the significance of transport energy estimation for a broader approach to mitigating the large energy load of mobility within university campuses. Investigating people's travel patterns and providing knowledge on transport energy consumption may be utilized to develop transport policies and effective strategies at a university campus. Ambitious goals of achieving a sustainable transportation system have the potential of leading to a sustainable campus approach which contributes to the sustainable development of large cities on a global scale.

5. Methodology

The methodological approach of this work towards the question is based on quantitative energy calculations and their comparison. The transport energy consumption of students residing on-campus is assumed to be distinct from the ones residing off-campus on an annual basis. To calculate the annual transport energy, there are several parameters to be processed such as travel distance in kilometres (D), the number of trips in a year (N), the energy consumption of transportation mode per km in kWh (C), and the average number of passengers for the transportation mode (P) to reach individual values in calculations. By processing these inputs, annual transport energy consumption values for different student groups and housing facilities are achieved.

Moreover, to see the proportion of the annual findings in transport energy and to be able to relate these values to another sector than transport, a series of annual calculations on household energy is conducted. For this operation, several parameters are used such as the gross floor area of the facility (GFA), the constant value of household energy consumption per square metre for different housing typologies (F) obtained from the Statistics Norway Database (Bøeng, 2014), the number of inhabitants at the facility to estimate the individual level of consumption (I). The findings from the calculations are presented in the Results section with graphic information. The evaluation of the results, comparison of different sectors, and the key factors influencing energy consumption are discussed in the Discussion section. The summary of significant results, the implications on sustainable campuses and planning strategies, and the evaluation of the work are mentioned in the Conclusion section.

5.1. Data Collection

Some portion of the dataset is provided by external sources such as SIS (Studentsamskipnaden i Stavanger) which is the operator of student housing facilities, Kolumbus that is the operator of the public transport network in Stavanger, GeoNorge data archive, and Statistics Norway. The rest is collected by conducting a questionnaire survey, observational research, and operations conducted in GIS (Geographic Information Systems). In this part, the description of collecting the datasets is mentioned in detail with the sequence (1) data on student housing facilities, (2) data on bus specification and operation, (3) transport behaviour survey for student housing inhabitants, (4) bus occupancy survey, and (5) GIS operations to process data and aggregate the necessary values for the calculations.

5.1.1. Student Housing Data

According to the data received from their office, SIS has 13 multi-dwelling housing facilities in Stavanger that are in different locations, with a total number of inhabitants of around 1800. The facilities harbour a variety of different types of apartments mainly classified as single rooms with their own bathroom, single rooms with shared bathrooms, single studio apartments, couple apartments, and family apartments. The accommodation of SIS housing is highly in demand by the students of the UIS. Many Norwegian and international students prefer these options over private housing due to reasons such as affordability, simplicity of the contract regulations, and plenitude of leisure activities.

It must be noted that six out of 13 housing facilities consist of a cluster of multiple buildings while the rest is of individual buildings. The data provided by SIS to be used in this research is as follows:

- Location of housing facilities
- Distribution of different types of apartments for each facility

The number of inhabitants per building is calculated by using the number of different types of dwellings in the facilities. Single rooms and couple apartments host one and two people respectively while family apartments are estimated to host three people on average. Thus, the number of people living in each building is calculated with a slight inaccuracy and the quantities are listed in Table 1. Furthermore, the student housing facilities are classified into two different categories: located on-campus and off-campus. The former consists of four facilities around the campus zone whereas the latter is spread out on a wide area between the campus and downtown.

The main reason behind this categorization is that the students living on-campus do not have a home-to-campus commute since they dwell on the campus. On the other hand, off-campus students need to use a transportation mode to access campus facilities, thus, the study investigates the impact of this difference in commute needs.

	Facility Name	Apt. w/shared bathroom	Apt. w/own bathroom	Studio Apt.	Couple Apt.	Family Apt.	Total Inhabitants
on-campus	1. Sørmarka	0	0	235	48	0	331
	2. Gosenmyrå	0	0	160	0	0	160
	3. Redboxes	0	40	0	0	0	40
	4. Rennebergstien	0	0	210	23	0	256
off-campus	5. Madlamarkveien	2	81	3	33	1	155
	6. Norvald Frafjords	24	12	8	12	0	68
	7. Jernalderveien	78	5	3	4	2	100
	8. Stareveien	0	0	0	12	45	159
	9. Mosvangen	53	0	8	10	1	84
	10. Gulaksveien	104	4	4	6	2	130
	11. Badehusgata	0	24	1	7	0	39
	12. Bjergsted	0	0	120	43	9	233
	13. Misjonmarka	0	0	29	8	2	51
	TOTAL:						1806

TABLE 1

5.1.2. Vehicle Specification

This study mainly focuses on public transport buses as the main mode of transport on the university campus to analyse the annual estimation of consumed energy. However, it is also common to encounter individual or collective usage of private cars for daily commuting instead of public buses. Thus, the annual consumption of this secondary option is also estimated using the methodology in order to explore the extent of transport energy consumption regarding the different transport modes.

Firstly, to obtain the necessary information for the estimation of the consumption of public transport buses, a dataset that includes specification and occupancy of the operating buses in the Nord-Jaeren zone, the zone that includes the campus and the city centre, was requested from Kolumbus officials several times. However, only a part of them is provided by Kolumbus. These include:

- General distribution of the number of electric and diesel buses in the fleet
- Energy consumption of each bus type per kilometre

This dataset is included in the parameters to determine the number of electric and diesel vehicles with their energy consumption value per kilometre. Secondly, although the number of diesel cars is plenty today, an average electric car is chosen as the vehicle type for the trips considering the promising growth in the use of electric vehicles in Norway and the evident detrimental effects of fossil fuels. (Lund, 2018) The consumption value of an average electric car is obtained from the online Electric Vehicle Database which presents the energy consumption of over 300 electric vehicles used in Europe with kilowatt-hour units per kilometre. (EV Database, 2023) The average value of the dataset is taken as the constant value for the annual estimations. Eventually, all the constant values are presented in Table 2 and used in the calculation process of transport energy as key parameters.

In addition, it is mentioned by the bus operator that the electric vehicles are only used in specific bus lines which does not include the buses arriving at the UIS campus. The service area of these electric buses only includes 1 out of 13 student housing facilities only for trips to the city centre. For this reason, the impact of the electric buses in the current situation is neglected since its significance is quite low considering the 7% share of electric buses among the whole fleet. It is also stated by Kolumbus officials that upon renewal of their contract in July 2026, they are ambitious to swap all the diesel buses with electric ones. In other words, all operating buses in Stavanger are most likely to run on electricity in 2026. This information became an inspiration for this research to investigate this scenario and the aftermath, as well as the drawback of waiting for 3 years to act on such a change, considering that this paper will be submitted in June 2023.

Vehicle Type	Number of operating buses	Number of seats per bus	Energy consumption per km (kWh)
Electric Buses	14	51	**1,5**
Diesel Buses	189	42 & 51	**4,3**
Electric Car	-	-	**0,2**
TOTAL:	203		

TABLE 2

5.1.3. Transport Behaviour Survey Description

A transportation habit survey is conducted targeting the university students in Stavanger that are dwelling in student housing facilities, which is the single option of student housing provided by the University of Stavanger, operated by SIS. The purpose of the survey is to investigate the transport habits of students in terms of home-to-campus commute and home-to-downtown commute. In other words, the survey seeks to answer how often the students travel to the city centre and the campus on the basis of where they are residing. The survey also aims to explore the different patterns in the travel behaviour of the two student groups: on-campus and off-campus. Such exploration provides input for the annual transport energy calculations to be further evaluated in the Discussion. Thus, the questionnaire is designed with a goal-oriented approach rather than aiming for an in-depth analysis of the aspects of the participant profile. Table 3 represents a demonstrative scheme of the questionnaire.

The target group of the survey only includes the students using student housing of SIS because of the limitations in accessing the location information of private homes of other students. Thus, a brief questionnaire with 70 seconds of average completing time is shared with this student group via social media groups and face-to-face surveying next to several student housing buildings. The questionnaire has 6 main questions on how often the participant visits the university campus and city centre in a week and the time spent on the two locations per visit, information on student housing location, and information on the transportation mode used for these travels.

The survey does not aim to achieve an equal contribution from each housing facility, instead, the deliberation is on collecting close amounts of answers from each designated student group: on-campus and off-campus students. This equal distribution of sample size is considered significant for an accurate comparison between the travel patterns of the two groups. One of the main considerations in the preparation of the survey is to keep it as brief as possible, under one minute, to encourage more students to participate since it may be challenging to have people involved with a long and time-consuming questionnaire. The questions are prepared accordingly as multiple-choice questions for the sake of presenting a convenient questionnaire to the participants. In all the questions except the last one about the used transportation modes, students are required to choose one of the answers provided. However, the last question allows students to select multiple choices based on their preferred transportation modes.

Questions	**Answers**				
1. Which SIS facility do you live in?	13 Student Housing Facilities in multiple-choice answers				
2. How many days per week do you travel to Stavanger city centre?	1	2	3	4	5+
3. How many days per week do you travel to the UIS campus?	1	2	3	4	5+
4. How many hours per trip do you spend in Stavanger city centre?	0-1	1-2	2-3	3-4	5+
5. How many hours per trip do you spend in UIS campus?	0-1	1-2	2-3	3-4	5+
6. Which transport mode do you usually use in these trips?	walk	own bike	city bike	bus	private car

TABLE 3

5.1.4. Observation on Bus Occupancy

Since the data received from the bus operator company is only limited to the number of operating buses and their energy consumption per kilometre, it does not lead to an estimation reaching values per capita to estimate transport energy consumption on an individual level for students. For this reason, an alternative method was applied to obtain the average passenger per bus value. Data was collected by simultaneously observing the buses on a specific bus stop while roughly counting the number of passengers inside the bus and reporting the seat availability data provided in the mobile app Kolumubus which is an indicator scale of the available seats on running buses in a range from one to five. One can argue that both observed sources are not fully reliable in terms of providing an accurate number of people. However, the objective of the observation is to achieve an average number of passengers value to be used in annual calculations. Considering the time constraints and the difficulty of accessing data from the private sector, this method appeared to be convenient to collect the necessary data to be used in the estimations.

Data collection was planned to be executed on a weekday for a continuous 12 hours starting from 7.00 in the morning until 19.00 in the evening. The designated day of collection was Thursday 11.05.2023. Bus lines labelled 6, 7 and X60 are observed in both directions at the bus stop Kjølv Egelands Hus which is the main bus stop in front of the largest building on the campus. The reasons behind choosing these three bus lines are that they are the main bus lines that pass through the bus stop all day and they operate between the campus and the city centre. The aspects noted down while collecting the data are as follows:

- The exact time of arrival at the bus stop
- The number of the bus line
- Whether the bus is articulated or small type
- Passenger count inside the bus
- Kolumbus app seat availability from 1 to 5
- Whether the bus is going to or coming from the city centre

Each passing bus is reported with these inputs. The information bus size is used to determine the seat number of the bus. Since the mobile app data is an indicator of empty seats, the indicating factor on the app is multiplied by the total number of seats in the bus to reach an average passenger number as a supplementary data source to the physically counted passenger number. The 18-meter-long articulated buses of Kolumbus are able to host 51 seated passengers and the 15-meter-long non-articulated buses host 42 seated passengers. Thus, these figures are taken into consideration as the maximum values while calculating the number of people through the mobile app data in accordance with the size of the bus.

5.1.5. GIS Operations

Geographic Information System (GIS) is an interface that enables to store, analyse, and manipulate geo-located data. Numerous types of operations are possible to aggregate refined results by bringing together several data sources. In this research, open-source and free-to-use software QGIS, licensed by GNU, is selected as the GIS tool. Mainly, there are two operations conducted in QGIS to estimate transport and household energy consumption.

The first operation is bringing together the input data about the facilities and the student housing buildings. The buildings are placed on the map by using the location information from SIS and FKB-Buildings dataset obtained from the GeoNorge website, which is a national data provider in numerous formats. Then, they are mapped in QGIS as shapefiles and the information is entered to the attributes of the buildings regarding the number of inhabitants and the distribution of apartment types. Furthermore, the gross floor area (GFA) data from FKB-Building is attributed to each building. After these processes, the building shapefiles with the information on their location, inhabitant number, dwelling number, and gross floor area are achieved. As the next step, population density (POPd) for each building is derived from the operation of dividing the total number of inhabitants for each building by the gross floor area (GFA). Then, the population density value is multiplied by 100 to achieve more reasonable figures that are larger than 1. These calculated figures, presented in Table 4, play a significant role in estimating the annual transportation and household energy consumption as well as in making comparative analyses for both.

Facility Name	Total Inhabitants	GFA (m^2)	POPd (Per 100m^2)
1.Sörmarka	331	9925	3,34
2.Gosenmyra	160	4198	3,81
3.Redboxes	40	700	5,71
4.Rennebergstien	256	4069	6,29
5.Madlamarkveien	155	4822	3,21
6.Norvald Frafjords	68	2029	3,35
7.Jernalderveien	100	3360	2,98
8.Stareveien	159	5292	3,00
9.Mosvangen	84	2947	2,85
10.Gulaksveien	130	4210	3,09
11.Badehusgata	39	2059	1,89
12.Bjergsted	233	8017	2,91
13.Misjonmarka	51	1404	3,63

TABLE 4

Secondly, a distance analysis is planned from the student housing buildings to the UIS campus and city centre. The results of the following operations are illustrated in Figure 1. As the initial step to this operation, the nearest bus stop from each student housing facility is located on the map. For the university campus and city centre, bus stops named UIS Øst and Klubbgata are chosen as the nearest stop from these locations respectively. The routes of bus lines 6, 7 and X60 are added on the map using Open Route Services add-in tool in QGIS starting from each housing facility towards UIS the campus and the city centre. By using the same add-in tool, two distance values from each housing facility to the campus and the city centre are calculated between the bus stops. Bus lines number 6 and number 7 use the same route from the city centre to the UIS campus while bus number X60 uses a different route. Due to this difference between the routes of bus X60 and the other two bus lines, the calculated distance values are not the same for X60 and the other two on some occasions. The relation between the location of a housing facility and bus lines is classified into three groups. The first category is the housing facilities that are located only on the way of bus X60, and the second group is the ones located only on the way of bus 6 and 7. The third group consists of the ones that are accessible by all the buses. For this reason, the route of the available bus line is taken into consideration in processing the distance analysis for the first two groups. The average of the distance values of three bus routes is calculated for the third group that is located on the overlap of all bus routes.

Furthermore, four of the housing facilities that are the furthest away from the campus, namely Gulaksveien, Badehusveien, Bjergsted, and Misjonmarka, are located outside the route of the three buses that operate through the university campus. For this reason, these four facilities require a transit bus while heading towards the UIS campus. This distance before connecting to the main three bus lines is also calculated in the distance analysis for these buildings. In addition, it is worth mentioning that the distance calculations do not include the walking distance between the building and the nearest bus stop. The distance parameters to be used in the calculations are derived from the measurement from bus stop to bus stop.

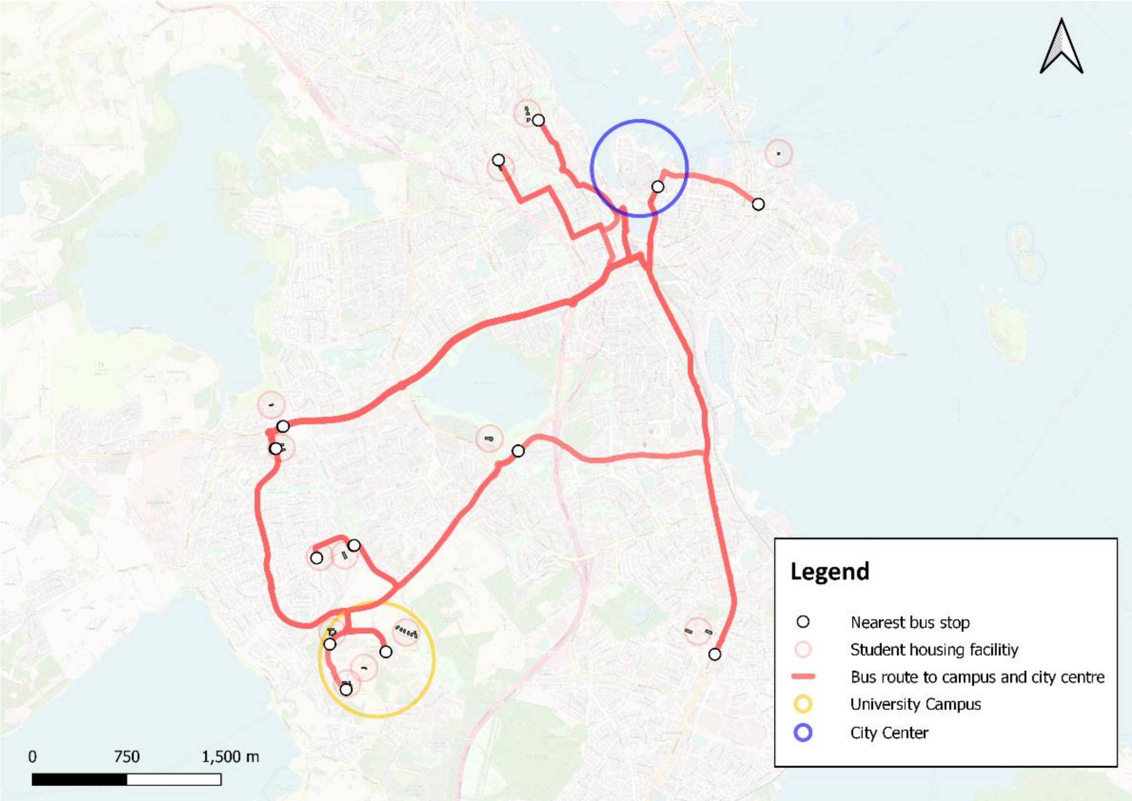

FIGURE 1

5.2. Annual Energy Estimation

This study mainly focuses on transportation as one of the major energy consumption sectors in a university context to explore the outcome of residing on campus facilities for a university student regarding the energy consumption from routine commuting. Primally, by using the input dataset collected from several sources, the transport energy consumption of students (T_p) residing in different housing facilities is estimated on a yearly basis as seen in Equation 1. This per capita value is later attributed to the housing facility scale reaching the value of transport energy consumption per building (T_b) as seen in Equation 2. By multiplying the building scale conduction by the gross floor area (GFA) of the building, transport energy consumption per unit area (T_a) is obtained as seen in Equation 3.

Finally, the household energy consumption per person (H_p) is calculated for each building using a different dataset than transport energy estimation. Kilowatt-hour (kWh) is determined as the common energy unit to compare results in different sectors except for the building scale energy consumption. This figure is calculated and reported in megawatt-hour (MWh) due to its larger amount when compared to other figures. The main objective is to be able to estimate the transport energy consumption of a single student residing in a specific housing facility and compare the transport energy of students dwelling on campus and off-campus. By calculating the household energy consumption of students living in any of the selected buildings, it is aimed to make a comparison between the energy consumption of a single student for the two energy sectors to explore the proportions between transport and household energy load.

Moreover, to investigate the transport energy consumption and its implications for the UIS campus more in-depth, further calculations are made considering a different scenario of the operating bus network regarding a major shift in the fuel types of buses from diesel to electric, as mentioned by Kolumbus officials, and the use of private vehicles by students in their daily commuting. The individual transport energy load from the diesel bus fleet is also converted to the amount of emitted CO_2 in kilograms per year resulting from the operation of buses.

5.2.1. Transport Energy Consumption

Annual transport energy by commuting via diesel buses is discussed in several different levels in this research such as the individual scale (T_p) reaching the values per person, the building scale (T_b) reaching the values per facility, the areal scale (T_a) reaching the values per unit area of m^2, and direct CO_2 emissions resulted from the trips via public transportation (T_c) in kilograms per year. The personal scale is used to analyse the consumption of single students from different buildings, and it is calculated based on four parameters. The first input parameter is the distance (*D*) between the housing facility and the city centre or the campus. This value is derived from the distance analysis in QGIS using Open Route Services network for each building separately and the unit is determined as kilometres. Regardless of the direction of the trip, each distance value is multiplied by two in the calculations to obtain a figure representing a round trip to either location.

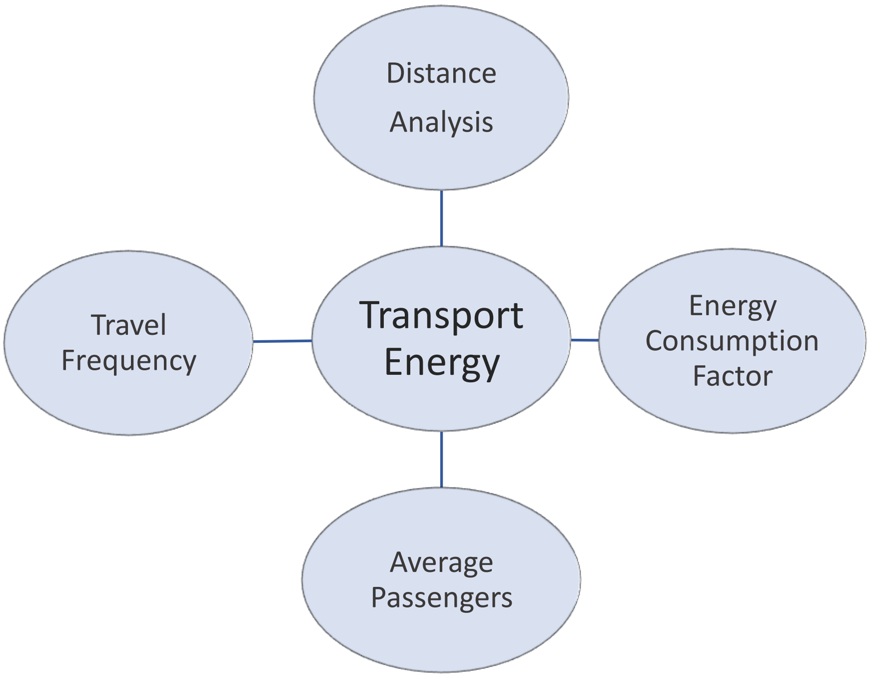

FIGURE 2

Components of Transport Energy Consumption

Secondly, the number of trips per year (*N*) is estimated by conducting the transport behaviour survey. The weekly number of trips for on-campus and off-campus students is derived separately from the survey, then, this value is aggregated to the annual scale by multiplying by the number of active weeks in a year. In this multiplication, the winter break and summer break periods are excluded from the whole year since many students travel elsewhere during these times and the campus facilities do not operate as usual. According to the University of Stavanger's academic calendar, the winter break is designated as 2 weeks while the summer break consists of 8 weeks. Therefore, the active usage of the campus facilities and the daily commute is determined to be for 42 weeks in a year and the weekly number of trips value is multiplied by this constant number.

The third parameter for transport energy estimation is the amount of energy used by the vehicle per kilometre (*C*). This data is obtained by contacting the operator of the public transport network in Stavanger and the values are presented in Table 2 as 4,3 kWh/km and 1,5 kWh/km for diesel and electric buses respectively. The final parameter is the average number of passengers (*P*) on the bus per trip. The last parameter takes the estimation of the transport energy of a single student from the vehicle scale to per capita (T_p) as indicated in Equation 1.

Moreover, the calculations in the building level are used to estimate the overall transport energy load of SIS students and the average consumption of a student residing in student housing facilities. Thus, after reaching the individual energy consumption value for transport, the results are multiplied by the inhabitant number of the same building to achieve the value of total transport consumption per housing facility (T_b), as seen in Equation 2. In order to compare the transport energy share of each facility more comprehensively, the figures of a single student's consumption are multiplied by the population density (POPd) of each building. Thus, the value of transport energy consumption per unit area is achieved for every building. In other words, the total transport energy consumption in the building scale is divided by the gross floor area (GFA) of the same building as in Equation 3 to achieve the consumption figures per m^2. However, these figures are multiplied by 100 to achieve the consumption value per 100 m^2 (T_a).

Finally, the energy consumption of the annual trips via diesel bus fleet is converted to direct CO_2 emissions resulting from the consumption of diesel fuel in public buses (T_c). The calculation method is demonstrated in Equation 4. This calculation is made based on the tank-to-wheel CO_2 emissions factor of diesel fuel which is 2.67 kgCO_2/litre. (Konečný et al., 2020, p.11) The consumption volume of diesel fuel per kilometre for public buses is noted as 0,83 litre/km. (Maimoun et al., 2013, p.1083) Therefore, the calculated distance of annual trips of students from different student housing facilities is used to calculate the amount of diesel fuel used for these trips. Then, the amount of diesel fuel is multiplied by the CO_2 emission factor to achieve the amount of emission in kilograms and this final value is divided by the average number of passengers in buses to obtain the direct CO_2 emission figures per person on a yearly basis.

$$\boxed{\text{Annual Transport Energy Consumption } \textbf{per person}} = T_p = \frac{2 \times D \times N \times C}{P}$$

EQUATION 1

$$\boxed{\text{Annual Transport Energy Consumption } \textbf{per building}} = T_b = \frac{2 \times D \times N \times C \times I}{P}$$

EQUATION 2

$$\boxed{\text{Annual Transport Energy Consumption } \textbf{per unit area (100 m}^2\textbf{)}} = T_a = \frac{2 \times D \times N \times C \times I \times 100}{P \times GFA}$$

EQUATION 3

$$\begin{array}{c}\text{Annual Direct } CO_2\\ \text{Emission from Transportation}\\ \textbf{per person}\end{array} = T_c = \frac{2 \times D \times N \times O \times V}{P}$$

EQUATION 4

$$\begin{array}{c}\text{Annual Household}\\ \text{Energy Consumption}\\ \textbf{per person}\end{array} = H_p = \frac{F \times GFA}{I}$$

EQUATION 5

C: Energy consumption factor of the vehicle (kWh/km)

D: Travel distance per trip (km)

F: Energy consumption factor of building typology (kWh/m^2)

GFA: Gross floor area (m^2)

I: Number of inhabitants

N: Number of trips per year

O: CO_2 emission factor (2,67 kg/litre for diesel buses)

P: Average number of passengers in buses

V: Diesel fuel usage of buses (0,83 litre/km)

5.2.2. Household Energy Consumption

The household energy consumption of a single student is estimated in order to monitor the proportion of the energy consumption in transportation to a distinct sector. The calculation is processed by using three input parameters shown in Figure 3. Firstly, the data on specific energy consumption per dwelling area (*F*) is obtained from the Statistics Norway website in kWh/m^2. The dataset includes consumption values for different housing typologies such as farmhouses, detached houses, row houses, and multi-dwelling buildings. The student housing facility cluster in this research consists of 12 multi-dwelling houses and one row-house typology, which is facility number 8 named Stareveien. Thus, the two consumption factors of these typologies are taken into consideration. These values (*F*) are 156 kWh/m2 and 180 kWh/m2 for multi-dwelling buildings and row houses respectively according to the dataset received from Statistics Norway. (Bøeng, 2014) Secondly, the gross floor area (*GFA*) of each housing facility is obtained from the FKB-Building dataset to be multiplied by the consumption factor in order to reach the household energy consumption per building. Finally, the number of inhabitants value (*I*) is derived from the dwelling quantity data of student housing facilities. Equation 5 demonstrates the calculation method of the annual household energy estimation of individual students from different student housing buildings (H_p).

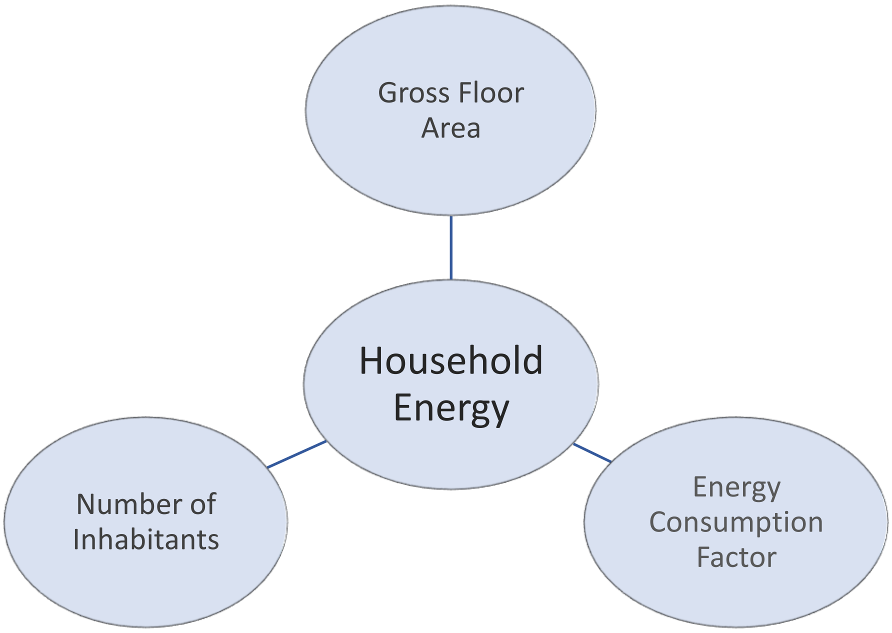

FIGURE 3

Components of Household Energy Consumption

6. Results

In this section, the findings from the mentioned methodology are presented with graphic information. These findings include survey results, processed datasets, and energy calculations. The sequence is as follows: (1) the result of the transport habit questionnaire for SIS students, (2) distance analysis from the student housing facilities to the campus and downtown by processing the Open Route Services data in GIS, (3) bus occupancy survey results, (4) calculation of transport energy consumption including different modes of transport and fuel types for buses, and (5) calculation of household energy consumption of the student housing facilities. These values from the findings are demonstrated in this section to be evaluated and compared in the Discussion part afterwards.

6.1. Transport Survey Results

The questionnaire was conducted with a total number of 87 participants from various student housing facilities. Considering that the estimation of total inhabitants resulted in 1806 people, participation is 5% of all students residing in SIS student housing. 46 of the total participants reside in off-campus housing facilities whereas 41 of them reside in on-campus buildings. In this section, survey results from all participants are presented to demonstrate the overall picture of transport behaviour.

The survey demonstrates that the vast majority of the SIS Housing residents use Kolumbus buses at a rate of 86 per cent. These bus lines are the only option for public transportation operating towards and from the university campus. However, using these buses is not the single mode of transport for students since some students reported that they use walking, cycling, and car sharing as alternative transportation methods alongside the bus network. Figure 4 illustrates the usage rate of each transportation mode separately among all participants. The closest alternatives to the public buses are walking and using the electric bike system that works by renting an electric bicycle from a designated station and dropping it back at another one, which is also operated by Kolumbus. Only 9 per cent of the students report usage of a private vehicle, which can be considered a decent amount for the sake of sustainable mobility within the campus. However, it must be noted that this percentage most probably does not represent the private vehicle usage rate of every student attending the University of Stavanger since the participants of this survey, residents of student housing facilities, mainly consist of international students.

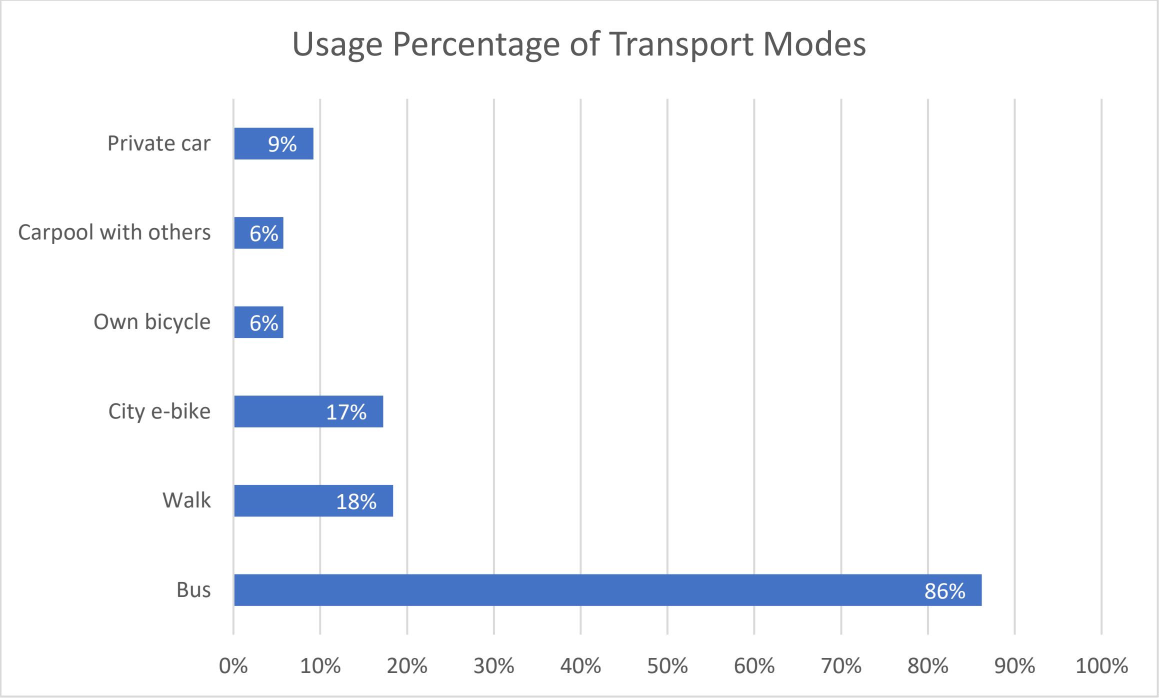

FIGURE 4

The trip frequency in the number of days per week of the participants' travel to the city centre and campus is illustrated in Figure 5. The bars in the graph represent the number of answers from the participants for each choice. The answers consist of five different choices from 1 to 5+, while the answer "5+" is considered as 6 days on average since it represents the amounts 5, 6, and 7. The result demonstrates that the number of days travelled to the campus is more than the amount to the city centre. In other words, the students of SIS tend to visit university facilities more often when compared to visiting downtown on a weekly basis. The mean value of a student's number of trips to the university campus is 4,15 while the mean value of visiting the city centre is 2,86 among all participants. These values indicating the average number of days a student travels to the two locations in a week are not the figures used in energy calculations. Instead, the specific average values for on-campus and off-campus students are used separately in estimating the transport energy as seen in Table 5. The average values of travelling to the city centre in a week for on-campus and off-campus students are 2,85 and 2,86 respectively, whereas the average values for trips to the UIS campus are 4,68 and 3,75 in the same order.

Another result of the survey demonstrates the amount of time spent in campus facilities and the city centre for each trip. The answers include the numbers of hours from 1 to 5+ per trip, and the answer "5+" is roughly considered as 6 hours on average while calculating the mean value of spent time since it represents the number of hours that are more than five. Among all participants, the findings show that students spend approximately three hours on an average trip to the city centre whereas the same average figure on a trip to campus facilities is approximately four and a half hours. Considering the presence of the sports centre, several cafeterias, and study areas on the campus, this difference between the two locations seems reasonable. Thus, it can be argued that students spend almost 50 per cent more time on the UIS campus than downtown on an average trip. Despite this information is not used as a parameter in energy calculations in the study, it can be a valuable insight into the travel behaviour of UIS students in further research.

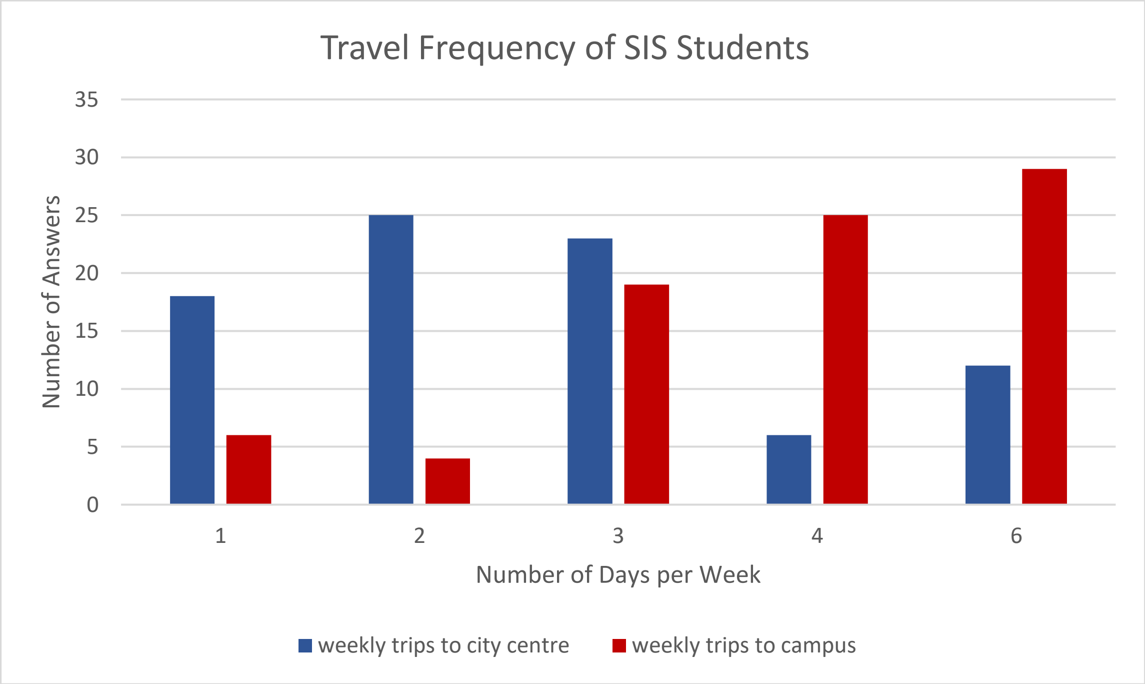

FIGURE 5

6.2. Distance Analysis in GIS

Distance calculation in QGIS through Open Route Services dataset is processed for each student housing facility separately for trips towards the campus and city centre. The nearest bus stops are located using Open Street Map in QGIS. By creating point features along the bus route, designated distance values are derived. The buildings numbered 1-4, which are the on-campus buildings, are attributed with values equal to zero in travelling to campus since they do not require a commute to campus. Buildings number 5 and 8 are only accessible via bus lines number 6 and 7, thus the distance value is attributed by calculating according to the route of these bus lines. On the other hand, building number 9 is only accessible via bus line X60 and the same process is applied accordingly by the route of X60. All other buildings are accessible by all the bus lines. Therefore, the distance value is determined by calculating the average of the sum of three bus lines for these facilities as listed in Table 5.

(kilometres)	**Distance to Campus**			**Distance to City**		
Facility Name	via bus X60	via buses 6 & 7	Avg. Value (d)	via bus X60	via buses 6 & 7	Avg. Value (d)
1.Sørmarka	0	0	**0**	6,93	6,94	**6,94**
2.Gosenmyra	0	0	**0**	6,65	6,66	**6,66**
3.Redboxes	0	0	**0**	6,93	6,94	**6,94**
4.Rennebergstien	0	0	**0**	6,98	6,99	**6,99**
5.Madlamarkveien	-	2,55	**2,55**	-	4,3	**4,3**
6.Norvald Frafjords	2,13	1,87	**1,96**	6,41	5,92	**6,08**
7.Jernalderveien	1,67	2,23	**2,04**	6,05	6,28	**6,2**
8.Stareveien	-	2,93	**2,93**	-	4,12	**4,12**
9.Mosvangen	2,53	-	**2,53**	3,86	-	**3,86**
10.Gulaksveien	5,69	9,89	**8,49**	3,85	3,85	**3,85**
11.Badehusgata	7,49	7,5	**7,5**	1,09	1,09	**1,09**
12.Bjergsted	7,64	7,65	**7,65**	2,83	2,83	**2,83**
13.Misjonmarka	8,04	8,05	**8,05**	2,68	2,68	**2,68**

TABLE 5

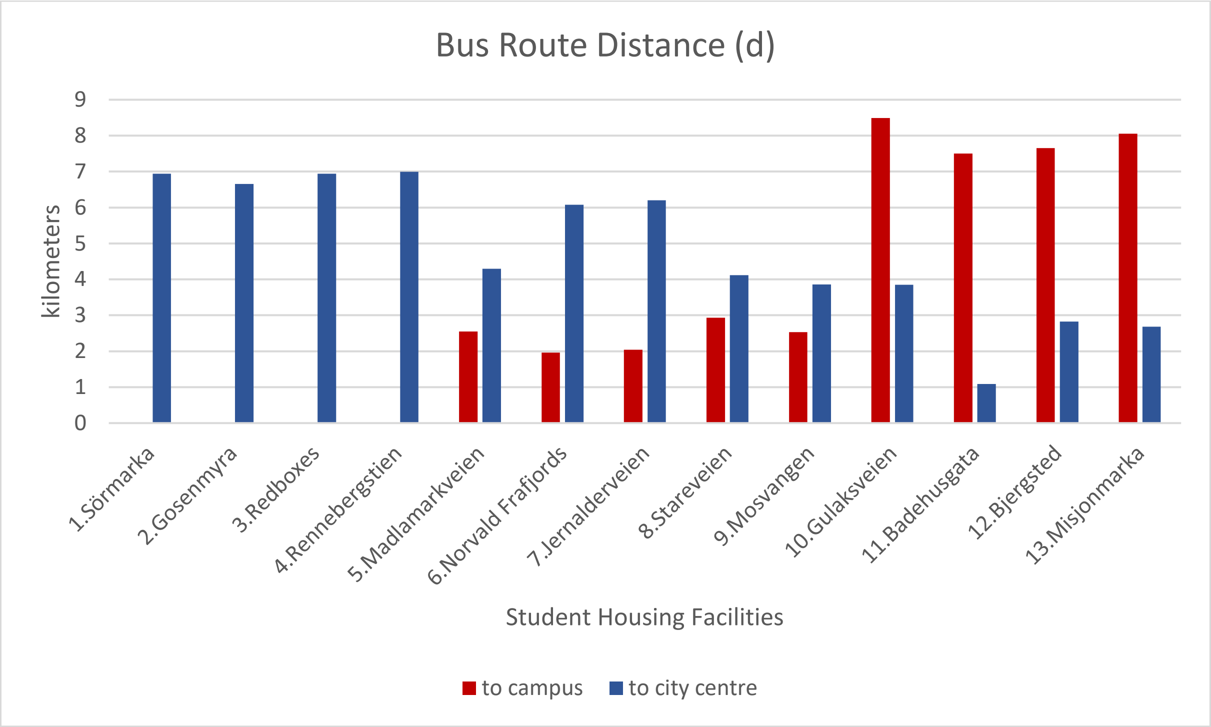

Figure 6

Figure 6 graphically illustrates the distance figures to be used in transport energy calculations for each housing facility. On-campus buildings have relatively higher figures regarding the commute to the city centre when compared to off-campus buildings and vice versa for the commute to campus. The maximum figure belongs to building number 10 with a value of 8,49 kilometres. The mean distance value from a building to the city centre among all student housing facilities is 4,81 kilometres whereas the mean distance value to the UIS campus is 4,86 kilometres excluding the on-campus buildings.

6.3. Bus Occupancy Analysis

The observation was conducted in a continuous 12-hour period on 11 May 2023 Thursday, collecting data from 242 vehicles operating in bus lines 6, 7, and X60. Observed bus stops were the two stops located on both sides of the road in front of the main building of the campus, namely “UIS ved Kjølv Egelands Hus A and B”. The passengers inside the bus were counted including the ones that are getting off at the bus stop, but excluding the ones that are getting on. The available seat indicator data from the mobile app was noted down for each bus with the information on the size of the bus stop which indicates the total number of seats on the bus. Thus, the passenger amount is aggregated as a supplementary dataset to the counting by observation.

The hourly distribution of the number of buses passing by the observation point is quite balanced for the three main bus lines with an average value of 20 buses per hour. It is observed that during rush hours, some additional bus lines start operating to satisfy the need instead of an increase for the three bus lines in the number of operating vehicles per hour. Many of the observed buses belong to bus line 6 with a number of 91 buses, followed by line X60 with 88 buses, and bus line 7 with 61 buses. The results show that 103 of the vehicles were articulated 18-meter buses while 139 of them were 15-meter non-articulated types in the 12-hour period. Figure 7 demonstrates the hourly total passenger load in all three bus lines. The peak hours in passenger numbers are seen as 8.00 in the morning and 15.00 in the afternoon. It can be derived that these two hours are the busiest times of the day in terms of the number of people using the buses. The hourly pattern also shows that after the rush hour in the afternoon, there is a steady decrease in the number of passengers.

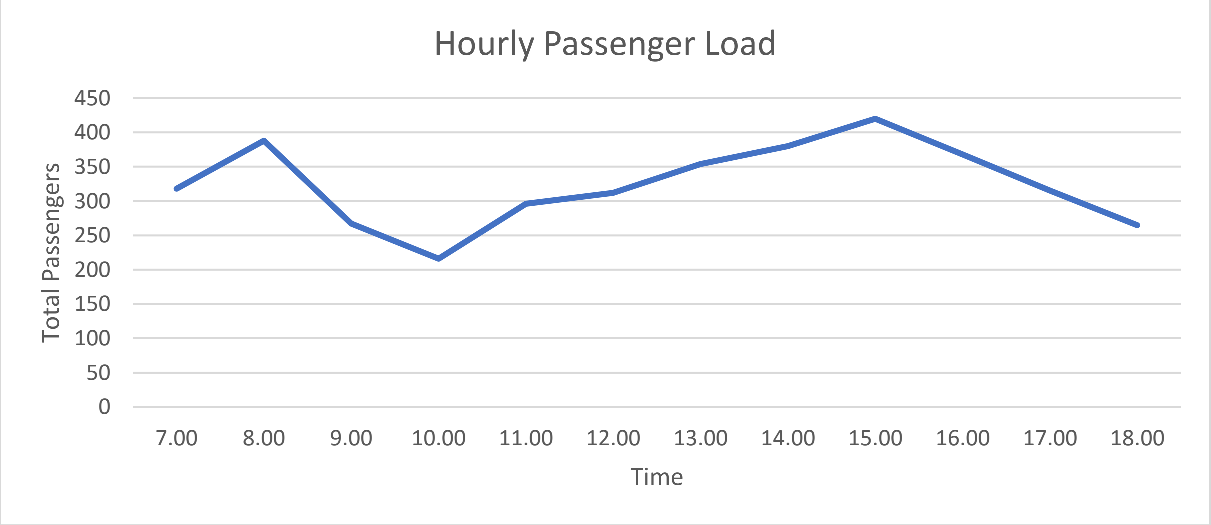

FIGURE 7

Figure 8 indicates the hourly passenger number per bus both for the counting method and aggregation from the mobile app data. The average number of passengers in a day according to the counting method resulted in 16,11 people per bus whereas the same value is derived as

12,85 from the mobile app data. The results present a slight difference between the two methods which can be caused by several reasons. Firstly, the figures derived from the app are more inaccurate when compared to the counting since they are calculated using the total seat number and a five-degree scale that shows the occupancy of the seats. Thus, the results from this operation are coarse values. Secondly, the data on the app may not be highly accurate since it is not easy to track the number of people on all buses with a hundred per cent accuracy. Another reason is that the app shows the available number of seats which means the people standing should not be considered as they do not occupy a seat. However, in the counting method, every passenger on the bus including the standing ones is noted down. For these reasons, it is not surprising to obtain different average values from the two methods. The most significant outcome of these results is that the hourly patterns of the findings from the two methods seem highly consistent. In other words, the hourly change in average passenger numbers for the counting method and the derivation from the app data appear to be parallel to each other. Thus, it can be argued that the two different finding datasets are noncontradictory. For the transport energy calculations, the value 16,11 obtained from the counting method is used as the average passenger number (p) on a bus.

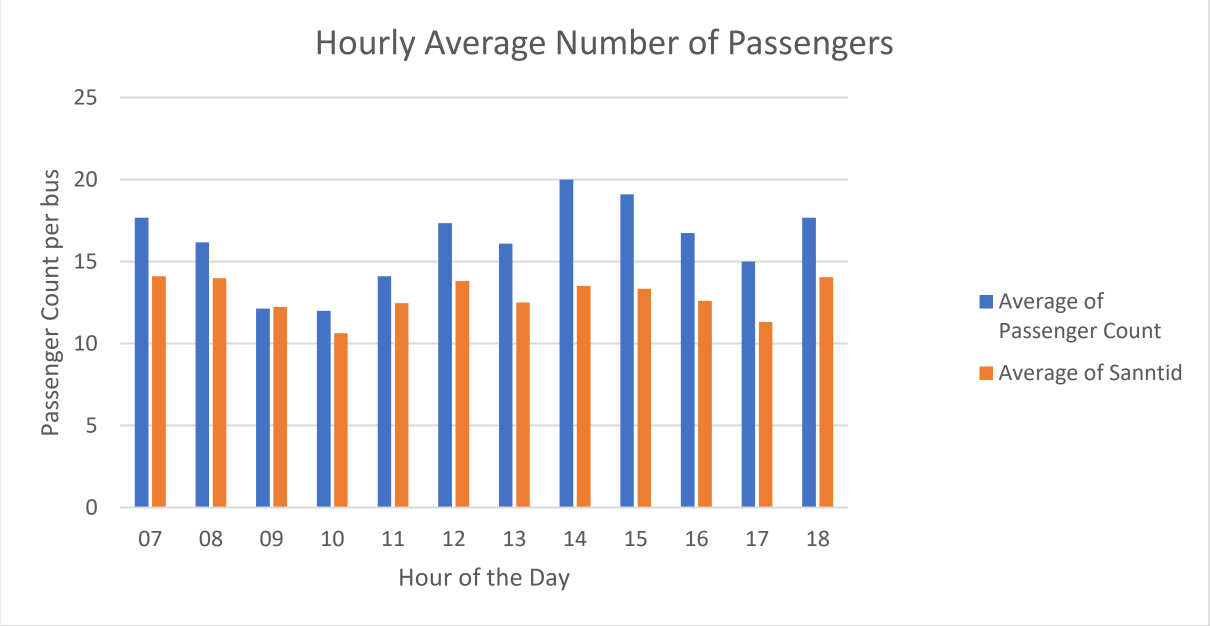

FIGURE 8

6.4. Annual Transport Energy Estimation

The annual transport energy estimations through the methodology are presented in this section. The findings are illustrated in graphic charts for every housing facility and the figures are noted in the tables. Table 6 demonstrates the yearly transport energy consumption of a single student from each housing facility (T_p), of a housing facility (T_b), and of a 100m^2 unit area (T_a) considering the use of public transport buses throughout the year. The reason behind the further calculation of transport energy to building and areal scale is to explore the extent of transport energy consumption and observe the correlation with the number of inhabitants and the population density of each facility. The buildings numbered from 1 to 4 represent the facilities located on campus while the buildings ranging from 5 to 13 are the ones that are away from the UIS campus. In other words, the total transport energy estimation of the first four buildings does not include a home-to-campus commute while the rest of the facilities necessarily include both trips, to the campus and the downtown.

Firstly, as indicated in Figure 9, out of the individual transport energy figures (T_p), the maximum consumption estimate belongs to the tenth building Gulaksveien with a value of 962 kWh per year for a single student residing in this building. Based on the calculation from the nearest bus stop, a student living in building number 2 at Gosenmyrå has the lowest estimate of energy consumption for transportation with a value of 425 kWh per year. The average transport energy consumption value among 13 housing facilities is 591 kWh per year. The four facilities ranging from 10 to 13 have higher consumption values than the average for a single student whereas the other nine buildings are below the mean value.

Secondly, the table also shows the transport energy consumption of each student housing facility as the sum of all inhabitants' share (T_b). This result is derived by the multiplication of the single-person consumption value by the total number of inhabitants for the same building and the figures are presented in megawatt-hours which is a thousand times larger unit than kilowatt-hours. Thus, Figure 10 illustrates the total transport energy consumption of a whole facility as the sum of the inhabitants' share. Building number 12 at Bjergsted stands out with a maximum value of 192 MWh per year due to its high figures for individual transport energy and number of inhabitants while building number 3 named Redboxes has the lowest facility consumption value with 17 MWh. The total annual transport energy consumption of all the buildings is calculated as 1026 MWh. When divided by the total number of 1806 students living in the student housing buildings, this grand total gives the result of an average student's transport energy consumption as 568,1 kWh per year.

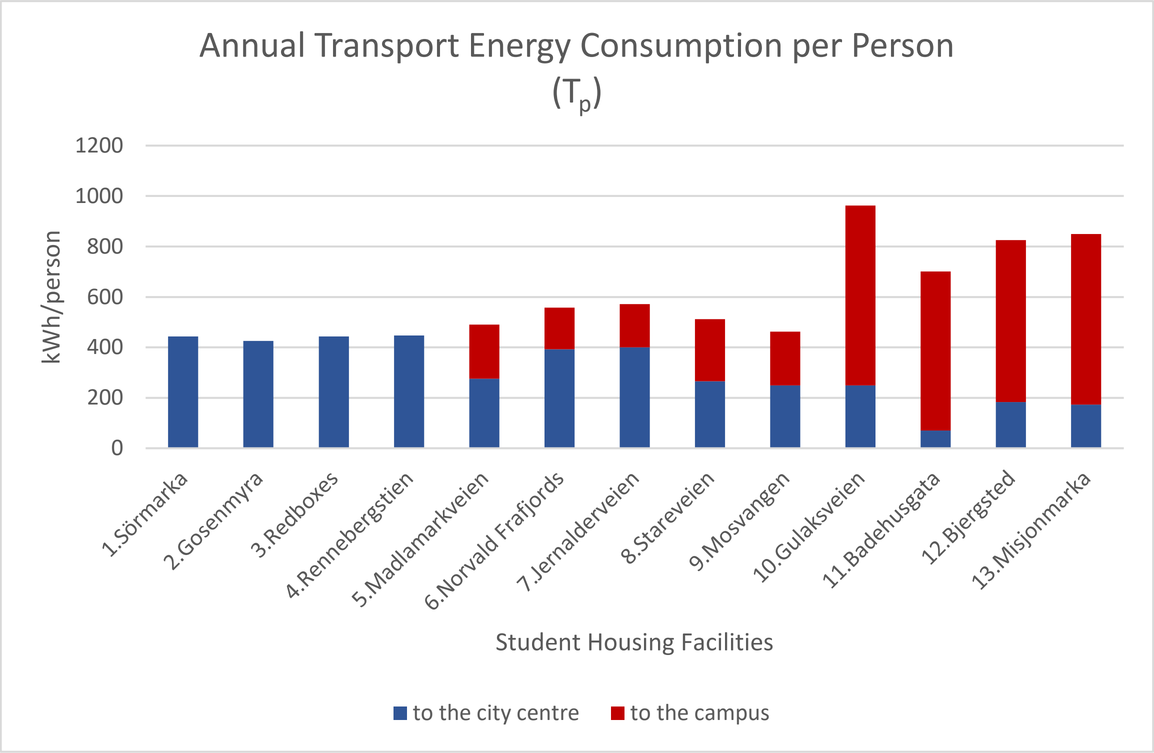

FIGURE 9

The third component of the table is the transport energy consumption per $100m^2$ of each building based on the inhabitants' individual consumption (T_a). These figures are the results of multiplying the individual consumption values (T_p) by the population density of the facility (POPd). The unit of the figures is a kilowatt-hour (kWh) and the average value between the 13 housing facilities is 2018 kWh/$100m^2$ annually. Five of the facilities have values higher than the average whereas the other eight facilities are below the average in terms of transport consumption per unit area. As seen graphically in Figure 11, building number 13 Misjonmarka has the highest value with 3087 kWh/$100m^2$ whereas building number 9 Mosvangen carries the lowest T_a value with 1316 kWh/$100m^2$.

(via Diesel Buses) **Facility Name**	**Annual Transport Energy Consumption per person (kWh) (T_p)**	**Annual Transport Energy Consumption of building (MWh) (T_b)**	**Annual Transport Energy Consumption per 100m^2 (kWh) (T_a)**
1. Sørmarka	443,46	146,8	1479,0
2. Gosenmyrå	425,57	68,1	1622,0
3. Redboxes	443,46	17,7	2534,1
4. Rennebergstien	446,66	114,3	2810,1
5. Madlamarkveien	490,13	76,0	1575,5
6. Norvald Frafjords	557,39	37,9	1868,0
7. Jernalderveien	571,87	57,2	1702,0
8. Stareveien	512,39	81,5	1539,5
9. Mosvangen	461,97	38,8	1316,8
10. Gulaksveien	962,43	125,1	2971,9
11. Badehusgata	700,97	27,3	1327,7
12. Bjergsted	825,94	192,4	2400,4
13. Misjonmarka	849,88	43,3	3087,2
Avg.:	**591,7**	**78,96**	**2018,0**
TOTAL:	**7692**	**1026**	

TABLE 6

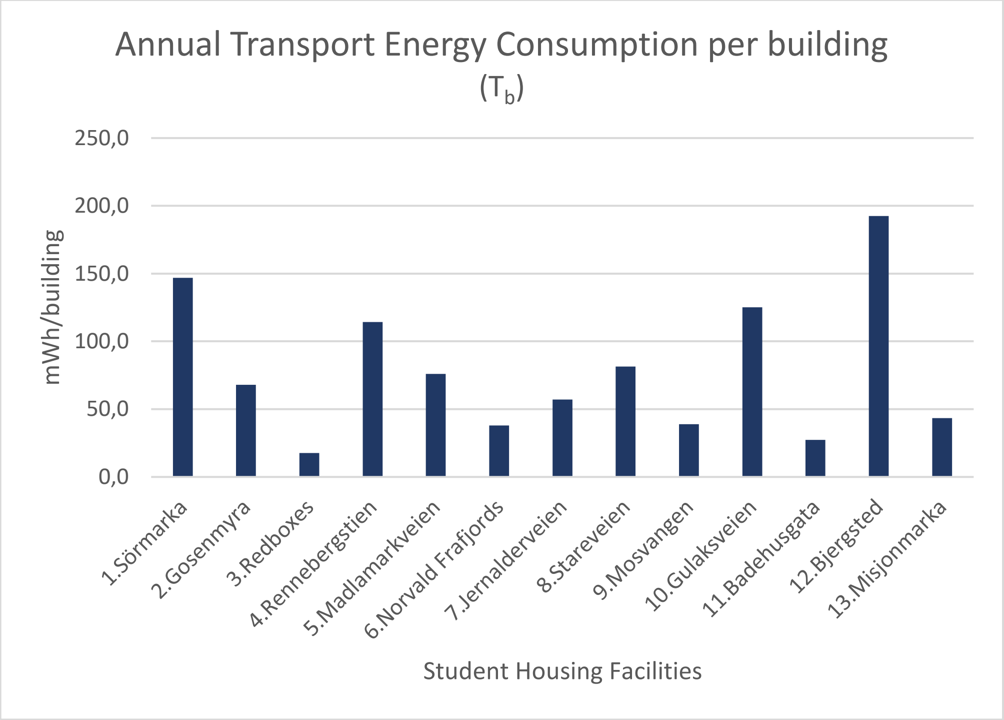

FIGURE 10

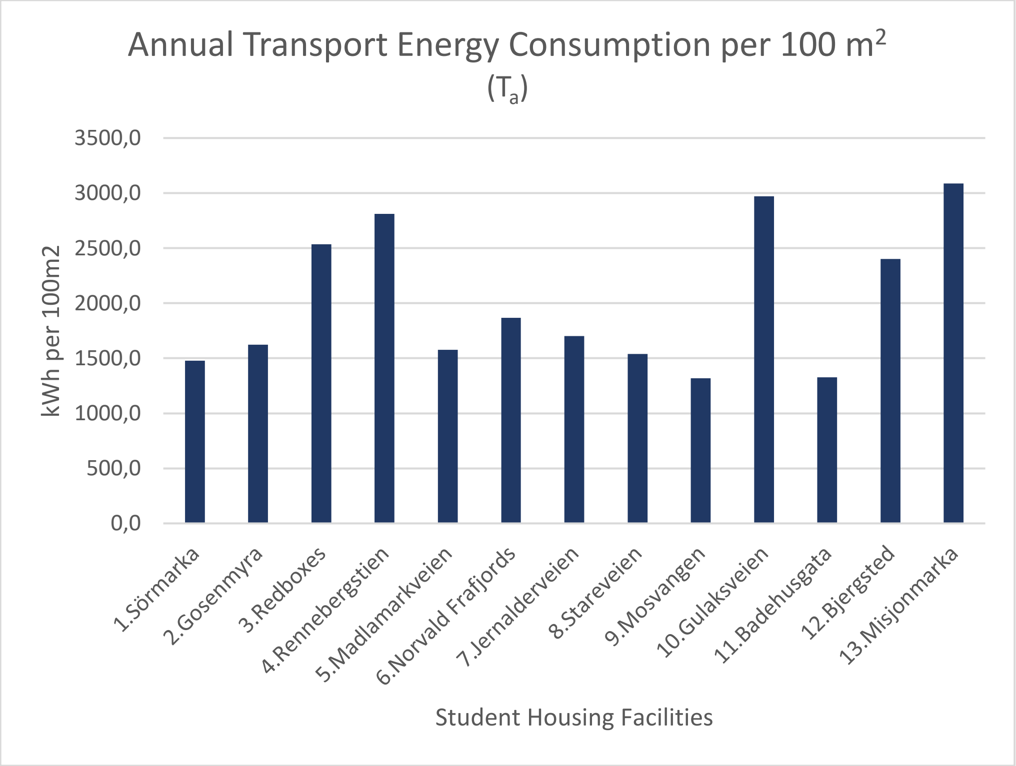

FIGURE 11

Furthermore, Table 7 presents a different set of results including the annual transport energy consumption of students in the probable scenario of a shift to a complete electric bus fleet (T_{p2}), the same consumption in the scenario of using a private electric car (T_{p3}) to travel between the housing facilities and the two target locations, and the direct CO_2 emission resulting from the energy use of diesel bus fleet (T_c) as today. The first two sets are calculated in kilowatt-hour (kWh) to be compared to their diesel bus equivalent values whereas the CO_2 emission figures are calculated in kilograms per year.

Annual transport energy consumption of the two electrified modes is illustrated together in Figure 12. Brown coloured bars demonstrate the transport energy load of a student residing in the student housing facilities considering the use of an electric car with only the driver inside the vehicle. The maximum consumption belongs to the students residing in building number 10 Gulaksveien with a value of 721 kWh/year and the minimum value is 318 kWh/year of a student from building number 2 Gosenmyrå. The average consumption by an average electric car among students from different facilities is 425 kWh/year.

The scenario of a complete shift to an electric bus fleet from diesel ones shows that the average transport energy consumption of a student living in student housing is 198 kWh/year. The maximum consumption in a year is 335 kWh and the minimum is 148 kWh by the electric buses. The distribution of the values over the housing facilities for the two electrified modes is similar to the estimation for diesel buses (T_p) since all the figures are dependent on the distance factor between the locations. However, the maximum, minimum, and average values are different for each. Their comparison and detailed analysis are to be made in the Discussion section.

Annual CO_2 emission of students commuting via diesel public transport buses is estimated and illustrated in Figure 13. An average student causes 290 $kgCO_2$/year by using the bus network for daily trips whereas a student living in building number 10 emits 472 $kgCO_2$/year and a student from Mosvangen emits 226 $kgCO_2$/year. The total direct CO_2 emission of every SIS Housing student is estimated as almost 504 tons/year via using diesel buses.

Facility Name	Annual Transport Energy Consumption via Electric Buses per person (kWh) (T_{p2})	Annual Transport Energy Consumption via private electric vehicle per person (kWh) (T_{p3})	Annual Transport CO_2 Emission via diesel buses (kg) (T_c)
1. Sørmarka	154,70	332,29	217,66
2. Gosenmyrå	148,45	318,88	208,88
3. Redboxes	154,70	332,29	217,66
4. Rennebergstien	155,81	334,68	219,23
5. Madlamarkveien	170,98	367,26	240,57
6. Norvald Frafjords	194,44	417,65	273,58
7. Jernalderveien	199,49	428,50	280,69
8. Stareveien	178,74	383,93	251,49
9. Mosvangen	161,15	346,15	226,75
10. Gulaksveien	335,73	721,15	472,39
11. Badehusgata	244,52	525,24	344,06
12. Bjergsted	288,12	618,88	405,40
13. Misjonmarka	296,47	636,82	417,15
Avg.:	**198,27**	**425,90**	**278,99**
TOTAL:	**358.093**	**769.184**	**503.854**

TABLE 7

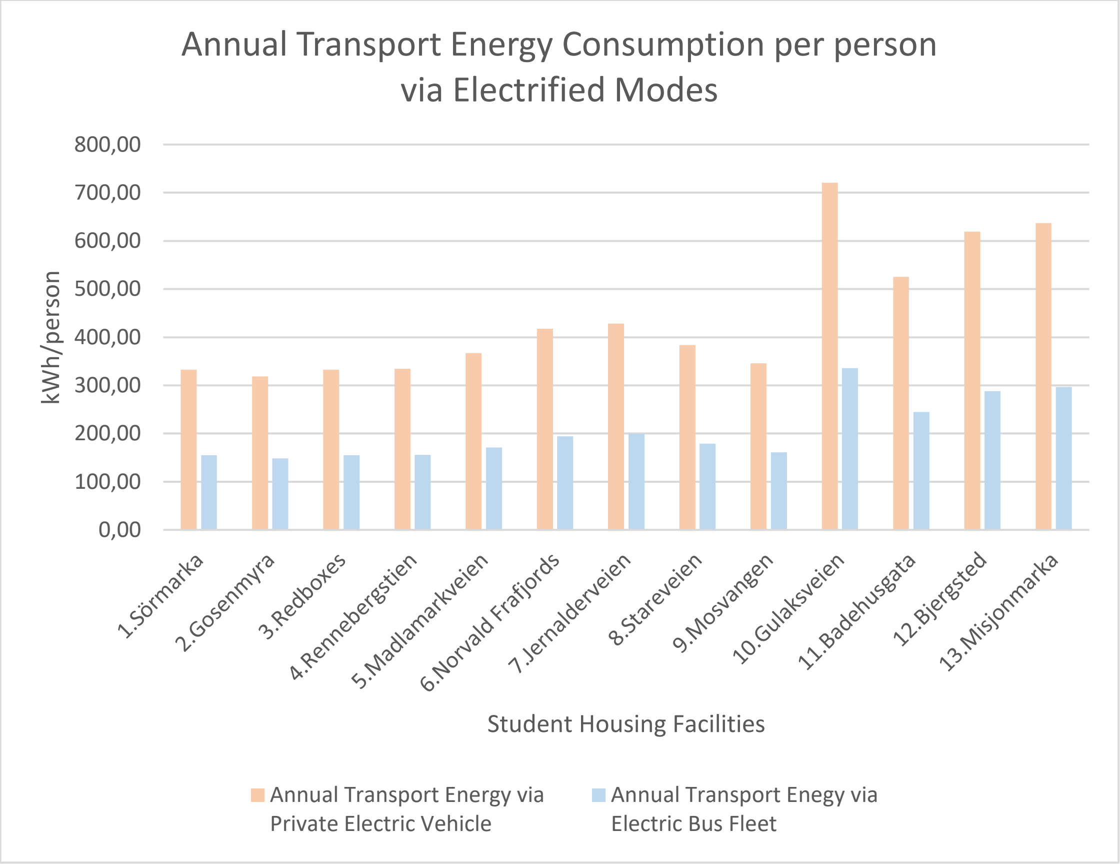

FIGURE 12

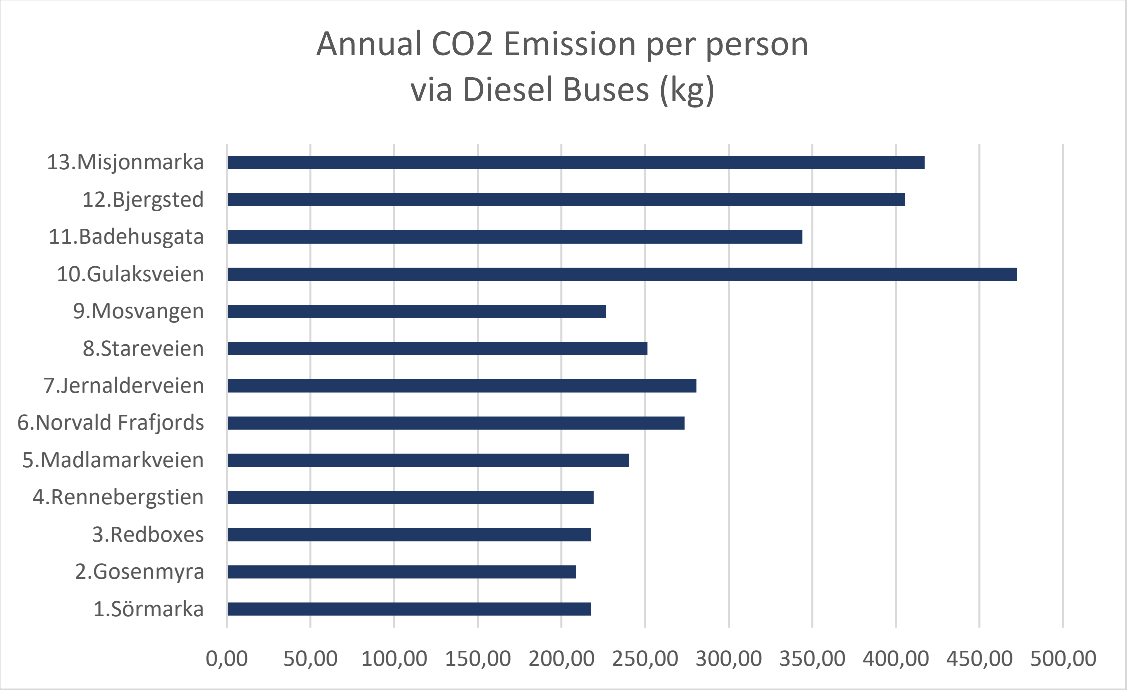

FIGURE 13

6.5. Annual Household Energy Estimation

The annual household energy consumption of a student from the student housing facilities is illustrated in Figure 14 separately for each building. The results are calculated based on three factors such as housing typology, the number of inhabitants, and the total used area in the facility. The average energy consumption value of a student is 4857 kWh/year. It is worth mentioning that these estimations are inversely proportional to the population density (POPd) of each housing facility. Thus, the 11th building Badehusgata has the maximum energy consumption per student with 8236 kWh/year and the lowest consumption per student belongs to the 4th building Rennebergstien with 2480 kWh/year. Although these estimations are average values, they provide valuable insight into the household energy performance of each building facility and the figures are compared to the transport energy estimation results in the Discussion section.

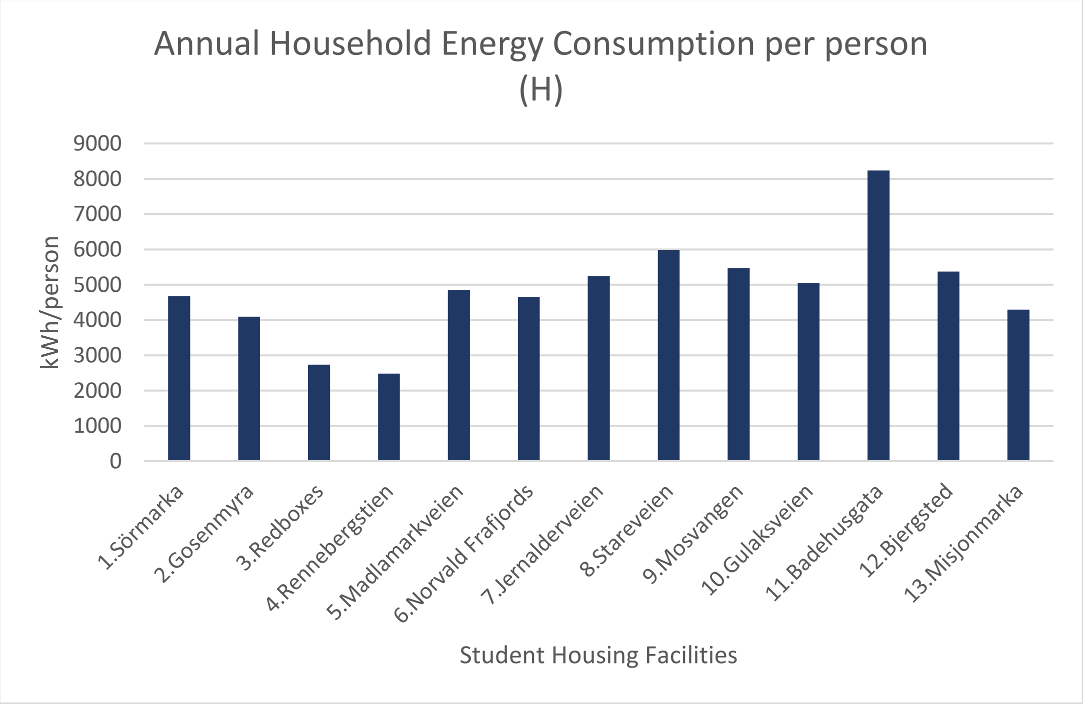

FIGURE 14

7. Discussion

7.1. Transportation and Household Energy Comparison

To analyse the quantity of transportation energy, estimated transport figures are compared to the energy consumed by households. The results show a dramatic difference between the two quantities. An average SIS student's annual transportation energy consumption is estimated as 591 kWh via diesel buses whereas the annual household consumption for the same student is 4857 kWh. In other words, a student residing in student housing spends more than eight times the amount of energy for households when compared to the energy for transportation via the diesel bus fleet in Stavanger. Figure 15 indicates the shares of transportation and households separately for each student housing building. Transport energy constitutes 11% of the overall consumption of the two sectors. Even with the case of a student living in a facility that requires a comparatively higher transport energy consumption and lower household energy consumption, such as Misjonmarka and Gulaksveien, the ratio of transportation energy does not go above 17% of the overall annual consumption of the two sectors. It can be observed that in opposite situations in the examples of Badehusgata and Mosvangen, the same ratio goes down to 8% of total consumption.

The findings of household energy consumption are derived by using the most updated energy factor for household typology published on Statistics Norway. (Bøeng, 2014) However, the dataset is last updated in 2014. Considering the constant improvements in energy efficiency measures, the estimated kilowatt-hour/kilometre value for each typology may correspond to a lower figure today. The trend in the dataset demonstrates a steady decrease in the magnitude of this consumption factor over the years. In 1995, the estimated average factor for all types of buildings is 211 kWh/m^2, whereas in 2012, the same value is equal to 185 kWh/m^2 with a gradual decrease. Thus, developments in household energy efficiency are likely to reduce domestic consumption in the future. For instance, even with a dramatic reduction in household energy by 50%, the ratio between households and transportation would be more than 1/4 regarding the improvements in transport energy as well. This is still a large difference yet underlines the massiveness of the ratio today between the two sectors.

The quantitative difference between the consumption of the two sectors is not surprising considering the research of Ridhosari and Rahman, who also found out that the energy consumed by building electricity usage in campuses is way higher than in transportation and other sectors. (Ridhosari & Rahman, 2020) It brings out the question of whether it is worth the effort of trying to reduce transport energy consumption while the buildings are consuming comparatively massive amounts. However, this huge difference in the quantities of energy used in two different sectors does not necessarily mean that one is eight times less significant in terms of dedicating resources to mitigate the excessive consumption and applied mitigation methods will result in eight times less magnitude. Since these are two different sectors with separate systems of complexity and purposes, the impacts of the measures to reduce their energy consumption may also result in different quantities. Transportation is an urban energy sector with a vast amount of contribution to energy consumption and carbon emissions, thus there is a need to dedicate more resources to research and practice to mitigate the environmental impacts. (Fichera et al., 2016, p.52)

Furthermore, to assess the situation from a broader perspective; although the methodology is applicable for any other location, these findings are context specific to Norway which is known to have a cold climate that requires high amounts of heating energy during the winter season. Thus, the gap between the consumption of different sectors may be smaller in another context where the household energy demand is lower due to climatic differences.

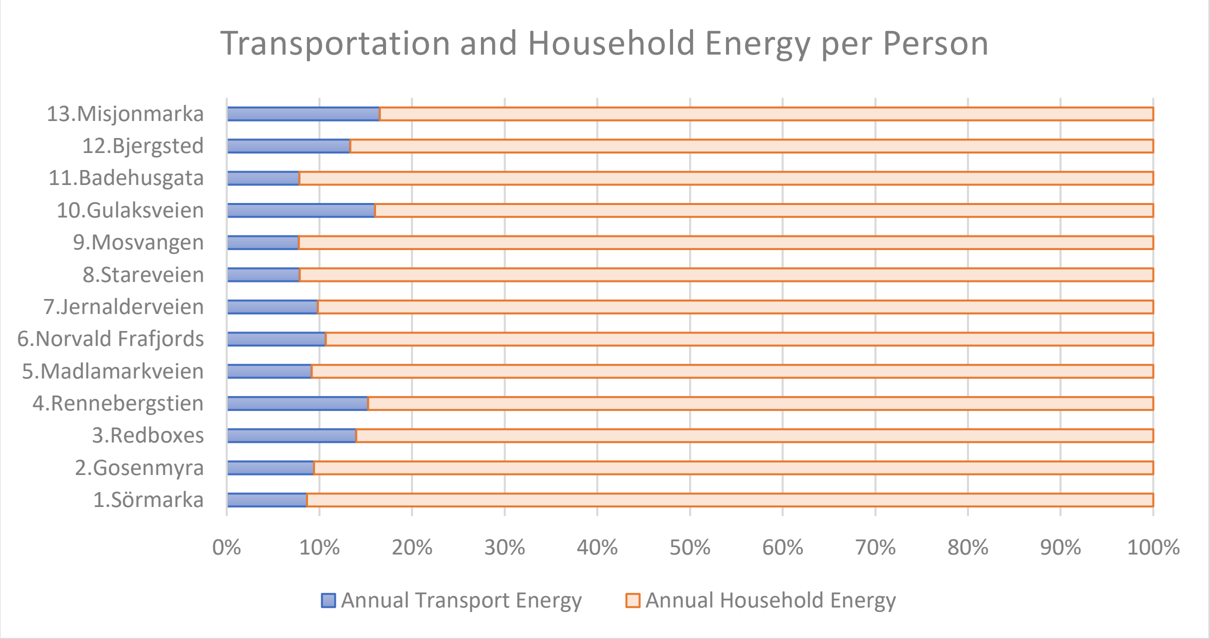

FIGURE 15

7.2. In-depth Transport Energy Estimation

In this section, the quantitative findings from transport energy estimation based on different transport modes and fuel types are brought together. The results for the two non-active transportation modes which are commonly used in the UIS are compared in subgroups. Firstly, the energy estimation regarding public transport buses is classified into two groups according to the fuel type. Since the information of a fuel shift from diesel to electricity in 2026 is obtained from the bus company, the energy calculation values are presented both for the diesel bus fleet and the electric bus fleet. Secondly, the estimation regarding private vehicle usage is subdivided into two groups considering the passenger count in the vehicle. As the results of the travel behaviour questionnaire demonstrated, the students at the UIS commonly use their private vehicles individually or collectively with other students. Therefore, the values for an individual trip and a collective trip with three passengers including the driver are generated separately. The estimations for private vehicles are made for an average electric car.

In order to analyse the proportions of different transport modes, a set of findings including the average, minimum, maximum, and total values of a student’s annual transportation energy consumption is illustrated in Figure 16. The image shows the transport energy consumption of students residing in student housing facilities in a year considering four different scenarios of using diesel buses, electric buses, private electric vehicles, and collective electric vehicles. The average section in the chart represents the mean values of all 1806 students in a hypothetical scenario where all students are considered to use the same mode of transport in a year, while the total section represents the overall consumption of students regarding the transport mode scenario. The maximum and minimum values demonstrate the peak values depending on the location of the housing facilities. All values except the totals are presented in kilowatt-hours while the total consumption of all SIS students is presented in megawatt-hours.

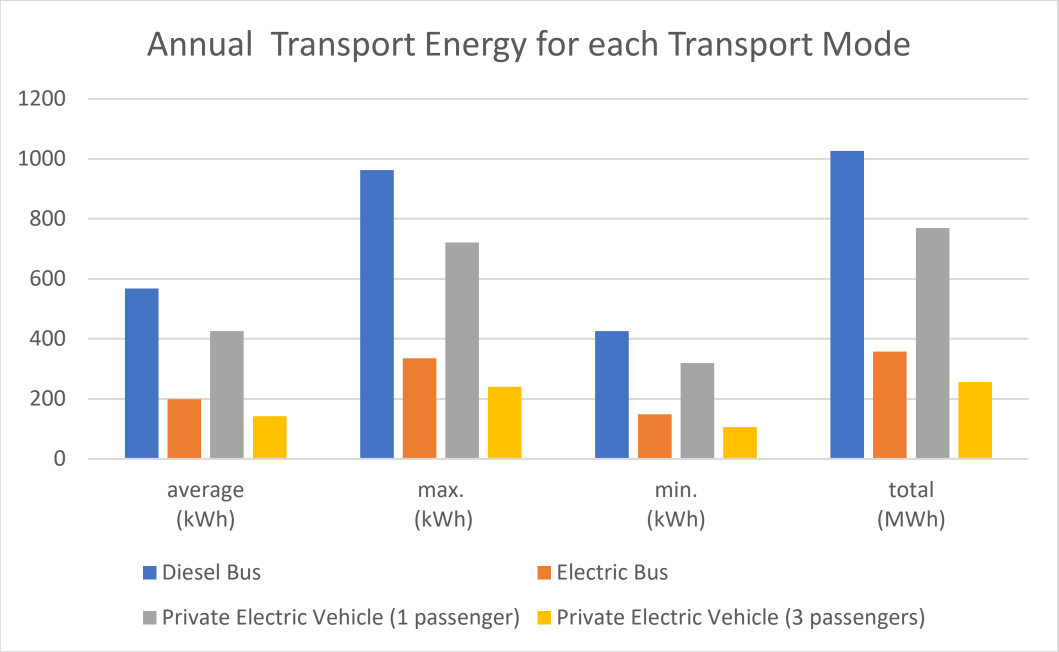

FIGURE 16

From the findings, it appears that an average SIS student consumes around 600 kWh of energy in a year for their daily commuting via the diesel bus network. A complete shift towards an electric bus fleet reduces this consumption to around 200 kWh/year, almost one-third of the diesel equivalent. The same goes for the individual use of a private vehicle and collective trips. An average electric car consumes 426 kWh/year for a student while the car-pool reduces this amount to 146 kWh/year per person.

The results show that driving an average electric car from the housing facilities to the campus and the city centre consumes slightly less energy than using public transportation with the current diesel bus fleet. However, after the shift to electric vehicles in the bus network, commuting with public transport buses seems to consume less than half the energy consumption via an electric vehicle. Thus, it can be stated that replacing a diesel car with an electric equivalent for the daily commuting of a university student reduces more energy than taking public diesel buses on a yearly basis. However, after the complete electrification of the bus fleet, an electric car needs to be collectively used by at least three students to ensure a lower consumption per person than the use of public electric buses in a year from an energetic perspective.

In 2026, after the shift to an electric bus fleet, the total potential consumption of students using the bus network reduces by more than 600 MWh regarding the hypothetical scenario of complete participation in public transportation. This potential reduction is quantitatively equal to the amount of annual total household energy consumption of 125 students within the student housing facilities. Therefore, the electrification of the bus fleet significantly impacts the annual transport energy consumption of SIS Housing students in a reduction amount equal to the household consumption of 7% of all inhabitants. However, this radical change is planned to come true in three years from now due to regulatory challenges regarding the contract agreement between the stakeholders.

Moreover, imagining that such a change is economically and practically feasible today and it could take place in 2023 regardless of the policy, the amount of potential transport energy that could have been saved in these three years is around 2000 MWh corresponding to the total amount of household energy consumption of three housing facilities Redboxes, Norvald Frafjords, and Misjonmarka during the three-year period. Although the energy-related consequences of the shift are significantly impactful in terms of reducing the annual transport energy consumption of students, being obligated to wait for three years to take an action causes a tremendous amount of loss in potential energy savings during this period which is comparable to the household energy of three whole housing facilities. Thus, these implications highlight the significance of a comprehensive transport development approach that includes the participation of all parties and prioritizes the improvements in urban nodes in the transportation network such as city centres, university campuses, or other urban attraction points. (Lopez et al., 2019; Filippo, 2014) Consequently, these findings show the crucial role of policy and regulation in developing a sustainable mobility system in terms of achieving practical progress.

7.3. Comparative Analysis of On-Campus Residency

In this section, the correlation between the annual energy estimation results and on-campus residency is further analysed. To understand the impact of the residency on campus, on-campus and off-campus housing facility clusters are brought together separately. The total and average figures of the two clusters regarding some key findings are presented in Figure 17. The estimations are based on the usage of diesel buses for daily commuting. The average number of inhabitants per housing facility is significantly different for on-campus and off-campus buildings. Facilities located around the campus accommodate approximately 200 students while the ones further away from the campus host a bit more than 100 students. Considering the number of housing facilities for the two groups, which are 4 facilities on the campus and 9 facilities away, it can be stated that on-campus buildings are clumped together with a higher number of accommodations whereas the other buildings are spread out in a quite large area between the city centre and the UIS campus with lower numbers of inhabitants. Due to the differences in the number of accommodating students and the number of facilities, it would be redundant to compare the results in overall figures for on-campus residency. Thus, the average estimation values per student are analysed for the two groups.

Considering the weekly trips to the city centre alone, the estimation shows that an average student dwelling on the campus consumes 440 kWh of energy by using diesel buses whereas an average student dwelling further away from the campus consumes 251 kWh per year. This difference seems quite large on its own as the figures are almost twice one another. However, due to the omitted home-to-campus commuting, campus residents do not consume energy for transportation to the campus while the others consume 408 kWh per person on a yearly basis. Thus, the overall annual consumption of a student residing away from the campus is 659 kWh and 440 kWh/person for campus residents. Moreover, the annual CO_2 emissions of the two groups draw a similar picture where an on-campus student causes 216 kg of direct CO_2 emission per year while an off-campus student is responsible for 324 kg of CO_2 per year. Therefore, it can be argued that annual carbon emissions resulting from the transportation of an average student at the UIS reduces by 33% upon residing in the facilities located at the campus.

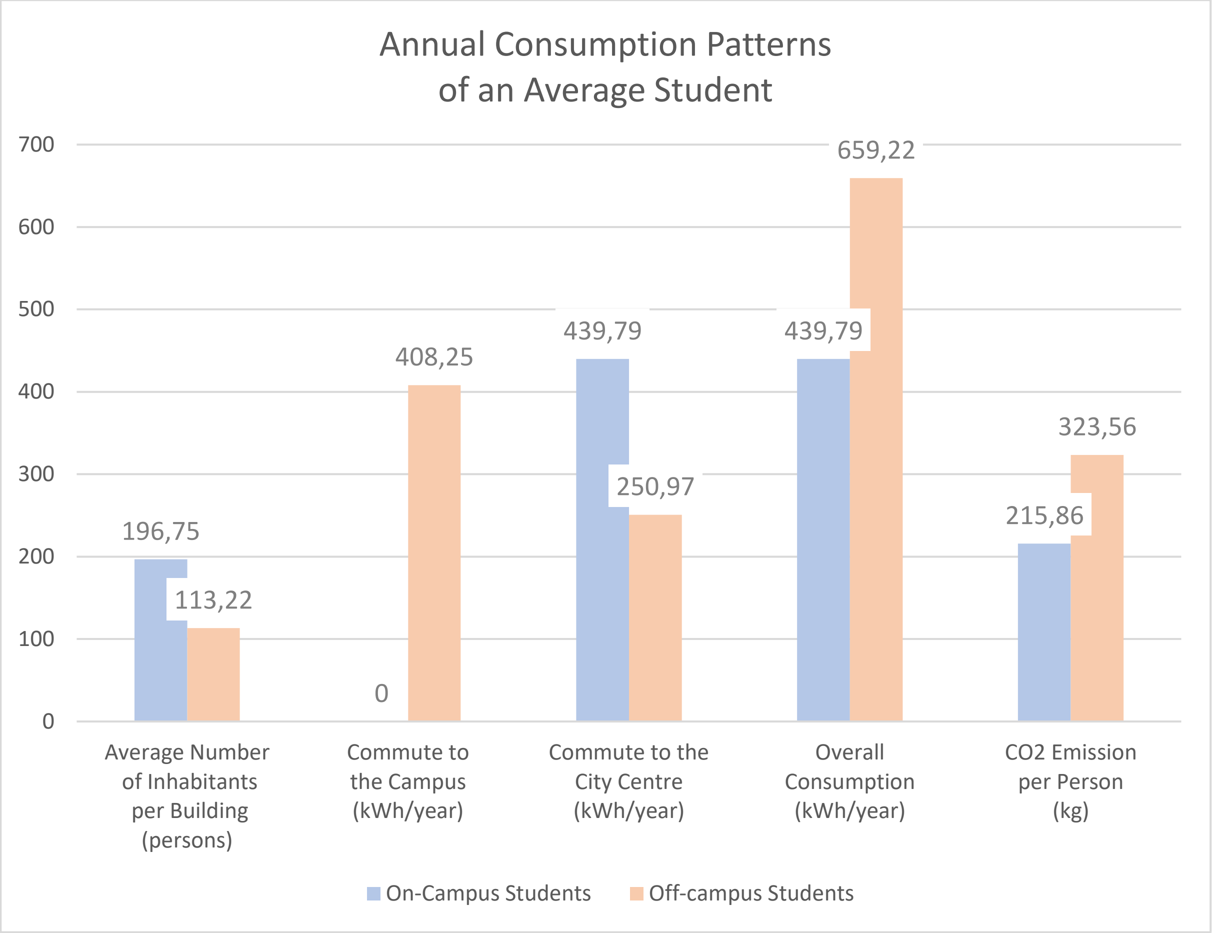

Figure 17

Although the decrease in carbon footprint is significantly lower upon campus residency, it would not be accurate to argue that new housing facilities should be built on campus for more students to dwell on campus territory without any thorough research investigating the student housing planning process in university campuses. Instead, promoting active transportation modes for these trips or increasing the functional features around the campus or housing facilities that could replace these trips for the students may be impactful solutions in order to achieve a sustainable campus. (Dehghanmongabadi & Hoşkara, 2018; Limanond et al., 2011)

7.4. Significant Factors Influencing Energy Load

The housing facilities have various values regarding the input parameters of the estimation method such as the distance to the campus or the city centre, the number of inhabitants, the used area within the building, and population density. Investigating the influence of these factors on the estimation figures provides insight into the correlation between the parameters and the results. To make such an analysis, annual household energy consumption per person (H_p) and transport energy consumption per area (T_a) are chosen to monitor the variations among the housing facilities in Figure 18. The reason behind selecting these values is that they are the findings dependent on the density factors of each housing facility and they represent the energy loads in relation to the used area and number of inhabitants.

The chart indicates that the buildings with higher densities have relatively lower household energy consumption on an individual scale whereas the transportation load per unit area is higher from the same standpoint. Buildings 11, 12, and 13 clearly show the correspondence between the density and the energy load for the two sectors as the steady increase in density value results in a decrease in the areal transport energy load and a rise in the household energy load. Since their proximity to the campus and the city centre is similar, population density is the dominant factor causing the energy loads. However, in the case of similar densities such as buildings numbered 1, 5, and 10; their proximity to the campus plays a significant role in the transport energy consumption load. The same pattern can be seen in the areal transport energy loads of the buildings in the latter observation.

Therefore, theoretically, it can be inferred that multi-dwelling housing facilities with higher densities and proximity to the campus result in less household energy load per person whereas the transportation load per area is higher. This implication indicates the significance of a densely built environment to improve the energy efficiency of the buildings on a per capita basis. However, these dense spaces need to be resilient to the increased transportation load. Hence, considering the consumption proportions of transportation and household sectors, a student housing planning approach should value proximity to the campus and develop compact design ideas, while promoting robust transportation strategies that are able to respond to the existing demand to achieve impactful results in the pursuit of a sustainable campus.

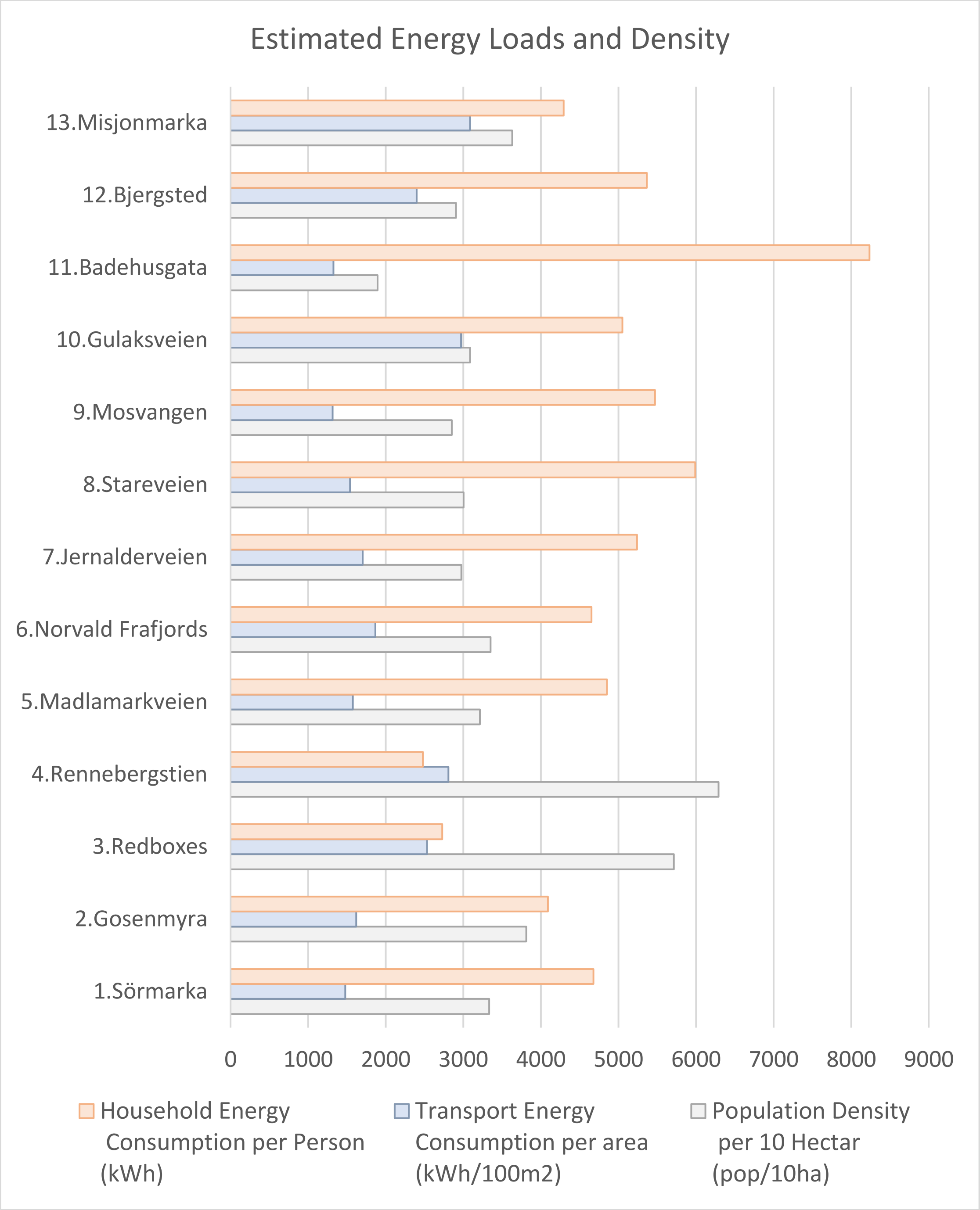
Estimated Energy Loads and Density
13.Misjonmarka
12.Bjergsted
11.Badehusgata
10.Gulaksveien
9.Mosvangen
8.Stareveien
7.Jernalderveien
6.Norvald Frafjords
5.Madlamarkveien
4.Rennebergstien
3.Redboxes
2.Gosenmyra
1.Sörmarka
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Household Energy Consumption per Person (kWh)
Transport Energy Consumption per area (kWh/100m2)
Population Density per 10 Hectar (pop/10ha)

FIGURE 18

8. Conclusion

8.1. Summary of Key Findings

This research has thoroughly examined the energy consumption patterns of the students of the University of Stavanger residing in Student Housing Facilities (SIS) in Stavanger. Mainly focusing on transportation energy, the annual consumption of the students based on weekly commuting to the university campus and the city centre for leisure activities is estimated by bringing together the data received from several sources. The annual household energy consumption of the accommodation facilities is also estimated as a supplementary operation to understand the proportions of the transportation energy by comparing it to another energy sector at the campus. Significant differences between the findings from the two sectors are identified where the annual household energy consumption exceeds that of transportation with eight times more value per year on average, especially due to the high heating demand in the cold climate of Norway.

However, the massive gap between the two sectors does not necessarily imply the insignificance of transport energy as it considerably contributes to the overall energy consumption. The study points out that substantial savings in transport energy can be achieved by promoting a collective use of private vehicles or a transition to an electric bus fleet from diesel in the pursuit of a more sustainable campus. On the other hand, the findings demonstrate that being obliged to wait for such a transition in the bus fleet leads to missing a massive energy-saving potential. Thus, it highlights the importance of a comprehensive and collaborative approach to transportation development in high-density areas such as university campuses.

In the context of proximity to campus, it was found that the students living on campus have less energy consumption on transportation and less carbon emissions on a yearly basis when compared to their counterparts residing further away from the campus. Thus, it needs to be taken into account as an input when constructing additional housing facilities that the proximity of the building to the campus impacts the annual transport energy consumption, as well as considering other factors such as promoting active transport modes around the campus and enhancing campus amenities to reduce the travel needs of students.

Another key factor in the energy load of housing facilities is the density of inhabitants. Densely built multi-dwelling buildings located near the campus show relatively less household energy per capita but the transport energy load per unit area is higher. This emphasises the significance of building high-density living environments with robust mobility strategies capable of managing the increasing transport demand to improve per capita energy efficiency.

8.2. Limitations and Future Research

This estimation results of the study are context specific to Norway whereas the used methodology is applicable to any other location. Quantifying energy consumption and carbon emissions is quite significant in communicating the impact of the transportation sector on climate change as it addresses the contribution of energy consumption. To make an insightful and accurate estimation, access to information plays a significant role in ensuring these aspects. However, it can be challenging to access the datasets that could provide a fruitful cluster to study the social, economic, and environmental impact of the built environment. Thus, this study tries to investigate the influence of transportation on sustainable campuses by bringing together information from several sources and collecting empirical data, due to the limited access to actual statistical data. The designed methodology discusses the annual contribution of different transport behaviours. In future work, incorporating actual data on significant factors in the research methodology and modifying accordingly may be beneficial for achieving a more comprehensive and precise estimation in high granularity. Thus, the findings provide more in-depth insight into the planning strategies related to sustainable mobility in higher education campuses.

9. Figure List

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