e/lecTUM

Our future is on the line – but is it online?

Project Report **elecTUM**

During our scholarship months, we united the topics climate change, the COVID-19 pandemic and our student life to study the new reality of TUM: that of online lectures. Under the lense of energy consumption, we decided to investigate whether online or on-site lectures would be the more sustainable option for TUM students. This investigation was done by developing a web-based calculator that had its input data based on the behavior of TUM students and on the general reality of students based in Munich.

Team	Maroua El Asri Alexander Holas Catherine Yngaunis Koch Joachim Leibold Alesia Prendi Tim Schlachta Anna Sophia Schmid Leonard Schmitt
Tutors	Maryam Tatari Sebastian Zäpfel
Supervisors	Prof. Dr. Peter Annighöfer Prof. Dr. Sara Diana Leonhardt

Preface by the Supervisors

Prof. Dr. Peter Annighöfer & Prof. Dr. Sara Leonhardt

Efficient and sustainable energy consumption remains to be one hot topic of our time. Our group Team elecTUM has decided to approach this topic. Based on what they have experienced during the Covid pandemic they focused on online lecturing, which, obviously, had a massive effect on our societal life. Online lecturing reduced social interactions in general or transferred them to a digital form. However, it has also influenced our individual energy consumption, for example by reducing individual moving radiuses, driving or flying, while increasing the energy consumption of individual households, because people were forced to spend more time at home and partly also shifted office times to their home.

ElecTUM has decided to analyze and compare online lectures with traditional lecturing approaches in university lecture halls. The intention was to not only compare the two approaches, but also to identify the main drivers of energy consumption, which could then be targeted in the future to render lecturing more sustainable.

As supervisors, we had the pleasure to accompany a highly motivated, self-organized and independent group of young students with a highly diverse studying background. During the whole period, we also had to rely on digital formats and exclusively met in virtual space.

Supervisor insights

For me, **Peter Annighöfer,** as forest ecologist and one of the supervisors, I could observe a very interesting project, from start to finish, from the first project idea to the final substantial report. But not only this, I also enjoyed seeing and accompanying, how the group organized itself and how it made use of the various skills they had within the group, by delegating responsibilities among one another, respectively.

What is your research interest or motivation for science? My own research is focused in interactions of plants and the resulting ecosystem structures, dynamics and services. In addition to deepening the understanding of the interactions between different ecosystem components, the aim of my research is to further increase the predictability of ecosystem dynamics. Based on this foundation, recommendations should be developed for a sustainable and result-oriented management of forest and agroforest systems.

What special experience from your studies/career would you like to share with the scholars? During my time as Master student, but also later on in my career as PhD student, I have mostly enjoyed group work quite a lot. I was allowed to experience how much more productive a group could be in comparison to a single person. However, for a group to function it needs guidance, supervision, and a group benefits from a productive atmosphere and encouragement. My intention was to offer advice and share my former experience with the group.

For me, **Sara Leonhardt,** it was a great (and, as JuAK supervisor) first time experience to supervise and work with the elecTUM team. I was deeply impressed by their independent and incredibly well self-organized working schedule, which they maintained throughout the entire period despite the difficult pandemic situation that confined all training courses and social interactions to a purely online format. I am also very excited about the team's results, which show that travel, in particular by car and from distant locations, consumes by far the most energy. This results provides a highly valuable roadmap for TUM but also other universities, suggesting that student access to housing close or on campus will greatly decrease energy consumption and increase the sustainability of education. Given the current global situation, this is more important than ever.

What is your research interest or motivation for science? My own research background is in ecology, specifically the interaction between plants and insects and how this interaction framework is driven by chemistry, affects ecosystem functions and responds to biodiversity loss. I have always been intrigued by the complexity of interactions and processes found in natural ecosystems, in particular in tropical ecosystems, and in the underlying mechanisms. I primarily want to understand and provide insight into hitherto unknown or little understood ecological phenomena. But I also want to use this knowledge to combat biodiversity decline and to contribute to sustainable solutions for conserving our natural ecosystems.

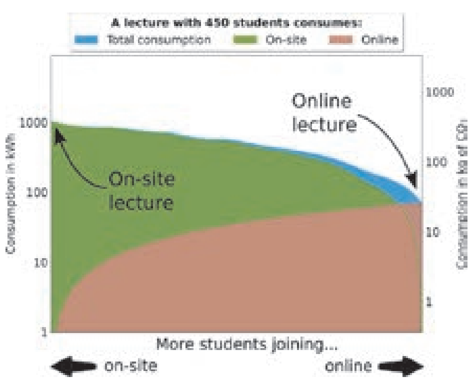
What special experience from your studies/career would you like to share with the scholars? I have always followed by own interests and path, which, occasionally did receive very little support or appreciation by colleagues. Even though I found it extremely hard to move on when told that (quote) "this (topic) is boring with a capital BEE..", I am glad I did hang in there. The hardest part is to free oneself from the opinion of others, but I think trying is worth it. ■

Let's talk about the dilemma between social interaction and energy saving

After approximately one and a half years of networking, research, and programming, a group of eight students at the Technical University of Munich (TUM) came to the conclusion: online lectures prevail when it comes to choosing the lecture format with the smallest energy consumption – mostly due to energy-intensive means of transportation, such as metro or car.

In early 2020, with the beginning of the COVID-19 pandemic, TUM either canceled its lectures or switched them to an online format. Since then, even with short periods of normalcy, the university has not yet fully returned to its pre-pandemic state.

In November 2020, when TUM lectures were mostly being held online, the mentioned student group got together to investigate whether different lecture formats had an impact on the overall energy consumption of TUM students. From the beginning, their aim was to develop a calculator which would determine, based on different parameters, what lecture format was the most energy efficient.



Even though the research group started its project with the aim of helping to reduce TUM's energy consumption, it is aware that, for most TUM students, on-site lectures are more interesting from a social interaction and mental health point of view. Hence, the student group recognized a dilemma: on one hand, they want to reduce the energy consumption of TUM lectures, which means switching to online lectures; on the other hand, they recognize the importance of social interaction and campus life for a healthy graduation. To approach this dilemma from the perspective of a TUM student, an interview was conducted with Clemens Zengler, one of the leaders of the Environmental Department of the Student Council at TUM.

A research group of eight TUM students found out that online lectures consume less energy than those on-site. The figure shows this result for a scenario with 450 students joining a lecture.

Clemens is doing his Master's Degree in Mechanical Engineering at TUM and studying at the Munich School of Philosophy. Since 2019, he has been a member of the Environmental Department of the Student Council at TUM. Here, he works to increase awareness of the environment and sustainability at TUM. In 2021, he took over the leadership of the department.

During his studies, he spent a semester abroad in Sweden to learn more about the way Swedish society tackles sustainability. In his free time, he likes to go running and hiking.

How did you experience it when all lectures were suddenly held online due to the Corona pandemic?

In the beginning, it was quite nice because I had a lot of time to do sports or meet friends from nearby. But I also noticed that I didn't follow the lectures very well. I was like, "oh, it's like a podcast in the morning," you know? I got very easily distracted and was often doing something else parallel to the lectures.

In the long term, what impact did online teaching have on your social life and mental health?

It definitely affected my social life because the pandemic started at the beginning of my master's program. So, I didn't have the chance to meet any new students. This, of course, had effects on the way I study and my interest in studying. Now, after two years of pandemic and only online lectures, I just recognized that I'm not that motivated anymore in studying. This is something I also recognized in my mental health. I feel very exhausted by all the studying.

In general, which lecture type do you prefer? Why?

When we're talking about just one specific type, I would definitely say live lectures. From my experience, the lecture material is better presented on-site, possibly because many lecturers are not very experienced in online lectures. But in terms of an entire study program, I would prefer a hybrid format, where I can also choose online lectures.

What role does sustainability and climate protection in general play in your life?

Sustainability is one of the major components of my life since climate change is one of the biggest problems humanity faces in this century. This is something which makes me very enthusiastic on one side, but also very depressed on the other side. I want to contribute to a solution to this problem as far as possible, but I'm also very afraid of the consequences of climate change.

What do you do to be part of the solution to climate change?

Firstly, I'm part of the Environmental Department of the Student Council at TUM. There, we try to represent the students' opinions on sustainability and to foster sustainable development by raising awareness. Secondly, in my mechanical engineering studies, I focus on energy systems and more specifically fluid mechanics. I try to focus on wind energy because I think that we need more sustainable energy sources.

Were you surprised by the results of our research?

I was very surprised. I was especially surprised by the amount of energy that live lectures consume. It is, from what I remember, 10 times higher than what online lectures require. That is such a huge difference.

What consequences do you draw from this for you personally? Does this change your preference for lecture type?

To be honest, this does not really change my lecture type preference because an essential part of studying is meeting other students. Without this, I could just do remote studies and that's not why I study. So, I would still go to live lectures because this social part is very important to me. I think that there are some parts in life, where you should try to reduce emissions, but we cannot stop everything that makes life good.

What about hybrid lectures?

I would go for the hybrid format to have a medium energy consumption.

Would you be willing to save energy and switch completely to online lectures as a climate protection measure?

No, since the purpose of being at the university is not only studying, but also networking and sharing new ideas with other people. Creativity, in particular, has suffered under online lectures, which led to a decline of good ideas. Better ideas come with attendance!

Moving away from the individual level, which consequences should the TUM Presidential Board draw from this insight?

They should draw the conclusion that a hybrid format is the best possibility for academic education. Therefore, the Presidential Board should advise the teaching staff to offer both options for as many lectures as possible.

The basis for this interview was our assumption that there is a dilemma between social activities of students and the high energy consumption of on-site lectures. After our discussion, what do you think? Does this dilemma exist?

That's a difficult question. In my opinion, this dilemma does not really exist. Apart from transportation, most of the energy consumption is accounted for by the university and the State of Bavaria. Therefore, TUM must think about which type of energy it consumes and how it can be reduced. Otherwise, the responsibility would be incorrectly shifted from TUM to the individual students.

Last but not least, do you think it is worth it to limit the students' social lives to save energy?

Definitely not! Studying is also there to socialize, discuss your future, and get inspired by other people. This does not happen, or barely happens, online. TUM itself is responsible for its energy consumption and should try to reduce it. This is not part of the students' tasks!

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Abstract
In this study, the energy consumption of online (streaming or video on demand) lectures is compared with on-site lectures. On-site lectures consume up to 2 orders of magnitude more energy than digital formats, making any combination of both always more energy intensive than purely online lectures. Transportation is the most energy consuming factor. In scenarios with a decreased impact of transportation, hybrid or purely on-site lectures can become more favorable in terms of energy consumption, especially if several on-site lectures are attended in one day.

1. Introduction

Since February 2020, the COVID-19 pandemic has not only changed societal life, but has also had a major impact on universities. Lectures and seminars, which were previously held almost exclusively on campus, were transformed into online events. In addition to far-reaching consequences for the social life of students and teachers, this also affected the energy consumption of lectures. As the production of energy often produces greenhouse gasses that are responsible for climate change and its negative consequences, their consumption should be as low as possible.

Due to its more than 45,000 students, the Technical University of Munich (TUM) holds a particularly large number of lectures. This gives rise to the responsibility of developing a teaching strategy that is as sustainable as possible by using as little energy as possible, given that Germany has not yet achieved an energy grid solely composed of renewable energy sources. In order to develop such a strategy, the question must be answered as to what extent the combination of online and on-site lectures can minimize the energy consumption of academic education.

By using energy consumption as the indicator of sustainability, the research question is limited to the environmental dimension of sustainability while neglecting the social and economic one. This perspective was chosen since energy consumption and its conversion in carbon dioxide emissions are clearly defined parameters for measuring the environmental dimension.

To answer the research question, the energy consumption of online and on-site lectures needs to be calculated separately. So far there are no known studies that discuss this issue. Therefore, no concrete examples existed on how to survey the energy consumption of lectures. To be able to calculate it, our own concept of categories of energy consumption was developed based on literature research. The data was acquired by on-site evaluation at the TUM campus, a survey conducted among TUM students and literature research.

From this, a model was created comparing the energy consumption of online and on-site lectures at TUM. A case study was then conducted in which various parameters of the TUM data were changed to illustrate their influence. The results of the study should assist the TUM Presidential Board to develop a sustainable academic education strategy after the COVID-19 pandemic.

2. Data

2.1 General considerations

The energy consumption of on-site and online lectures can be divided into different subgroups (Figure 1). In-person lectures require the students to travel to the university, which can be done individually, e.g. by car, or using public transport. During the lecture, the equipment of the lecture hall and the electronic devices of the students need to be considered. If lectures are attended online, the students' electronic devices, the equipment of the workroom and the action of streaming the lecture live or on demand have to be taken into account. Here, it is important to recognize that the electronic devices used might differ between online and on-site lectures. The energy consumption is given in kWh and can subsequently be calculated in equivalents of CO_2 emissions in kg using the conversion factor of the German power grid for 2020, 0.366 kg CO_2/kWh. (Icha, Lauf, and Kuhs 2021)

2.2 Data acquisition

To answer our research question, to what extent the combination of online and on-site lectures can minimize the energy consumption of academic education, the two scenarios – online versus on-

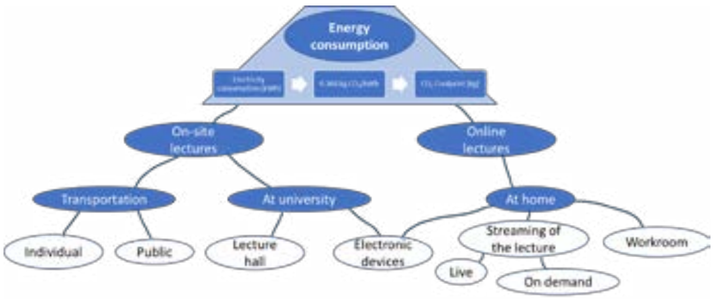

Figure 1: Categories of energy consumption of online and on-site lectures. The upper section shows the relation between the electricity consumption and the carbon dioxide footprint. Branched from the upper section, two different sources of energy consumption are defined: on-site and online lectures. For each lecture type, the factors contributing to its energy consumption are further specified.

site – have to be calculated first. As seen above in Figure 1, the calculation involves many variables, which are mostly determined by literature research. The electricity consumption of a typical lecture hall is researched by an on-site evaluation of the consuming devices, in which the light bulbs, beamers, and power supplies were counted. This on-site evaluation is combined with the inventory list cited below (See "At University"). The specific data of the students of TUM regarding transportation and electronic devices is investigated using a survey (see below) and our own measurements (see Supplementary Information, SI).

Transportation
Means of transport that are considered are car, motorcycle, bike, and on foot for individual and regional train, metro/municipal railway/tram, and bus for public transport. For car, motorcycle and bus, the energy consumption needs to be converted from kg CO_2 to kWh using the conversion factor from above [1/0.366 kWh/(kg CO_2)] for the use in the calculator. All values are listed in Table 1 SI and Table 2 SI. The travel time of the students is based on the survey.

At university
During an in-person lecture, the electricity consumption of the lecture hall and the electronic devices of the students and the lecturer are considered. Based on all lecture halls of the TUM (see Table 3 SI), the "Hörsaal 1, Interims II" (see Figure 1 SI) was chosen as representative for a modern, medium sized lecture hall with 449 seats. For comparison, lecture halls with less than 100 seats are defined as small, whereas halls with more than 500 seats are defined as large in this work. A list with the inventory and electricity uptake of the lecture hall's infrastructure can be found in Table 4 SI. Some students are expected to use electronic devices during the lecture. How many actually use them and what kind of device is queried in the survey. Electronic devices considered for on-site lectures are smartphones, tablets/iPads, laptops. The electricity uptake of these devices is listed in Table 5 SI.

At home
If the lecture is attended online, the electricity uptake of the used electronic device, the equipment of the student's workroom and the data transmission via the internet are considered. In this scenario, desktop PCs and additional screens are included in addition to the other devices. Based on a request to the student housing administration, a typical workroom has a LED lighting bulb with 13 W. For the internet connection and usage, a router, access and the infrastructure (core network; in the case of video on demand: data centers) are electricity consuming segments (see Table 6 SI).

2.3 Survey
The implementation of the calculator required, among other things, the collection of specific behavioral data from TUM students. This included information on transportation, electronic device use, and average streaming hours. To obtain this information, a survey was established. Given that the questionnaire was to be used to create the calculator, accurate data collection was required, while simultaneously keeping it simple and short, to increase the number of participants. The preliminary draft of the survey was created in August 2021, and a month later, after many rounds of feedback with the group members and supervisors, the final version was

determined. In the first week of October, the survey was launched on the platform “evasys”.

The survey consisted of six parts:

i. Personal information (questions about age, semester, course of study).
ii. Transportation – before the pandemic
iii. Transportation – on-site lectures (expected transportation when on-site lectures are reintroduced)
iv. Lectures, courses, semester (number of attended lectures, number and types of devices used)
v. Living situation
vi. Satisfaction and well-being

The questions from (i) to (v) were used as part of the calculator’s database. The questions from (vi) served as an interesting source of information for the qualitative evaluation of the students’ satisfaction with their experience of university during the pandemic as compared to before.

Prior to its usage in the calculator, the survey data was post-processed in an effort to cast it into a form accepted by our model (see section 3). Here, several simplifying assumptions were made:

- **Faculties**: The study programs indicated by the survey participants were binned under the corresponding faculty name in order to structure them into larger groups. Hereby, the bins were chosen so that similar study programs (in terms of lecture style) could be grouped into faculties (e.g. Mechanical Engineering and Aerospace Engineering). Very specific study programs with few participants were equally grouped together.

- **Transportation**: Students were only assigned one means of transport. Students using multiple means of transport were assumed to use only the most expensive one, energy wise, unless they were traveling to the university exclusively by bike or on foot. In this case, students were assumed to travel only by bike (if used) or by foot. The travel time remains unmodified.

- **Device types**: Here, a similar strategy to the transportation was applied, i.e. students were always assumed to use only the most expensive device, energy wise. Additionally, during on-site lectures (i.e. answers about the used device types before the pandemic), students were assumed not to use a desktop PC or any additional monitor. Moreover, during online lectures (i.e. answers about the used device types during the pandemic), additional monitors were only allowed in conjunction with either a desktop PC, a laptop or a tablet.

Acquiring participants was particularly challenging, especially since new COVID-measures were introduced during the conduct of the survey, which reduced the effectiveness of some forms of advertisement. Many different methods with their respective design layouts were used to spread the word about our survey, including:

- Publishing on our website;
- Outreach to the student councils of the various departments;
- Posts on Instagram, notably on the accounts of TUM: Junge Akademie and the environmental department (Umweltreferat) of TUM;
- Slides with the survey in the student union cafeteria;
- Posters;
- Sharing within our circle of friends;
- Publicity through and appearance in online lectures; and
- Newsletter of TUMJA.

The survey was officially closed in the first week of December with a total of 224 participants.

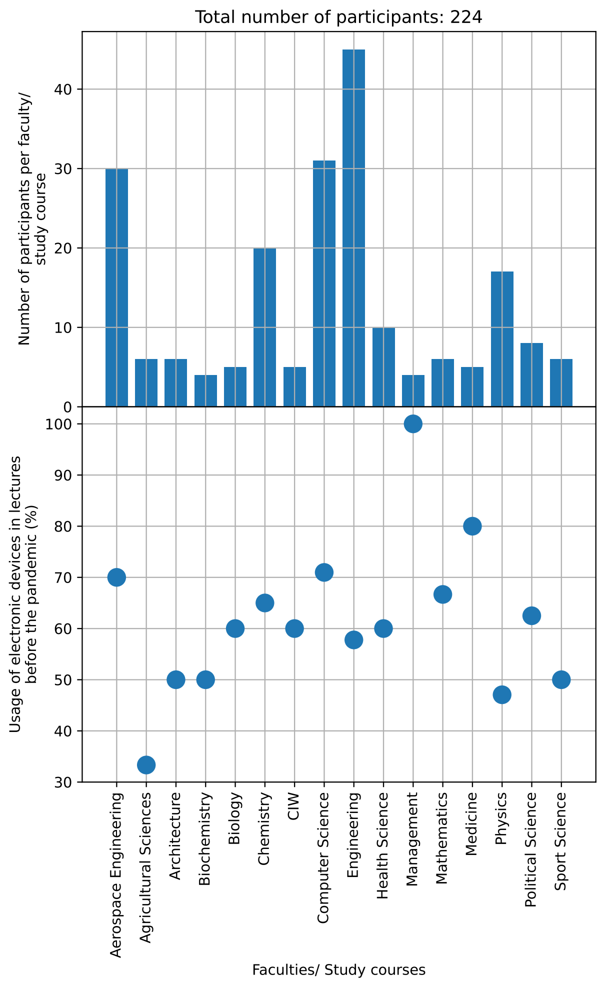

Figure 2 illustrates the participation in the survey across the different (binned) faculties, as well as the usage of electronic devices before the pandemic, i.e. the value used for on-site lectures. Table 1 also shows some averaged results obtained from the survey. It should be stated that these are only for illustrative purposes and do not represent the data used in the following calculations. Here the full statistical data obtained from the survey was utilized.

Lectures per day [a)]	2.7
Most used device type during on-site lectures [a)]	Laptop
Most used device type during online lectures [a)]	Laptop (+ additional screen)
Average travel time to university (min)	53
Most used means of transport	Subway

Table 1: Important averaged results obtained from the survey. These are only for illustrative purposes and do not actually represent the data used in the following calculations. [a)] Value for the Faculty of Mechanical Engineering, see section 4.

3. Methods

In this section, the general approach to calculating the consumption of lectures, both online and on-site will be discussed in detail. This approach is implemented in the ELECCALC toolkit,[1] which is under active development.[2] The discussion will be split into two main parts, one for the calculation of on-site lectures and one for online lectures. Both of them combined then constitute the hybrid scenario.

3.1 On-site lectures

The power consumption of on-site lectures $W_{\text{on-site}}$ is given by

$$W_{\text{on-site}}(n_{\mathrm{S}}) = W_{\mathrm{LH}} + W_{\mathrm{T}}(n_{\mathrm{S}}) + W_{\mathrm{D,off}}(n_{\mathrm{S}}), \tag{1}$$

where W_{LH} describes the consumption of the used lecture hall, W_{T} the consumption caused by transportation to the lecture hall and $W_{\mathrm{D,off}}$ the consumption of all electronic devices used during the on-site lecture. n_{S} is the number of students participating in the lecture. These different contributions can then be broken down further:

1 Available under https://electum.ja.tum.de/

2 https://github.com/AlexHls/ElecCalc

The lecture hall consumption W_{LH} consists of a base consumption, accounting for

- Blackboard lights
- Stair lights
- Amplifiers
- Microphones
- Cameras
- Other, lecture hall specific contributions.

If so specified by the user, beamers will be added to this base consumption if available for the respective lecture hall.

The consumption due to transportation W_{T} is given by

$$W_{\mathrm{T}} = \sum_{n_{\mathrm{S}}} \frac{2 \cdot W_{\mathrm{MoT}}}{n_{\mathrm{lpd}}}, \tag{2}$$

where W_{MoT} is the consumption of any given means of transport (MoT), e.g. a bus, which in turn is given by

$$W_{\mathrm{MoT}} = \begin{cases} P_{\mathrm{T}} \cdot d_t \cdot t_{\mathrm{travel}}, \\ m_{\mathrm{CO_2}} \cdot f \cdot d_t \cdot t_{\mathrm{travel}} \end{cases} \tag{3}$$

depending on whether the energy consumption per km, P_{T} or the produced amount of CO_2 (m_{CO2}, which is converted into $\mathrm{W\,km^{-1}}$ by a conversion factor f) is known. Furthermore t_{travel} the travel time in minutes, which is converted by d_t into kilometers traveled. Lastly, in eq. (2), the consumption of the individual MoT is then multiplied by 2 to account for the travel to and from the university and scaled by the number of lectures per day n_{lpd} to only account for the contribution to the specific lecture under investigation.

To establish which MoT is used by the students as well as the respective travel time, the survey data described in section 2 is used to get a multidimensional Gaussian kernel density estimate (KDE) using SCIPY (Virtanen et al. 2020). Here the bandwidth is selected using Scott's Rule (Scott 2015). This KDE is then used as a likelihood function to re-sample the survey to the number of students taking part in the lecture. The sampling is done using EMCEE, a pure-Python implementation of Goodman & Weare's Affine Invariant Markov chain Monte Carlo (MCMC) Ensemble sampler (Foreman-Mackey et al. 2013), whereby every student is assigned one walker. After the sampling, the result is averaged over several samples.

The last term in eq. (1), $W_{\mathrm{D,off}}$ is given by

$$W_{\mathrm{D,off}} = t_{\mathrm{lec}} \sum_{n_{\mathrm{S}} \cdot u} P_{\mathrm{D}}, \tag{4}$$

where t_{lec} is the lecture duration and P_{D} is the power draw of a given device, e.g. a laptop. Here, the number of students is modified by a percentage u which specifies the fraction of students using electronic devices during on-site lectures, as specified by the survey described in section 2. Similarly to eq. [eq:transp], the used devices for each student are sampled from a KDE using EMCEE.

3.2 Online lectures

Online lectures are calculated similarly to on-site lectures described in section 3.1: Their consumption is given by

$$W_{\mathrm{online}}(n_{\mathrm{S}}) = W_{\mathrm{LS}}(n_{\mathrm{S}}) + W_{\mathrm{L}}(n_{\mathrm{S}}) + W_{\mathrm{D,on}}(n_{\mathrm{S}}). \tag{5}$$

Here, W_{LS} describes the consumption of the lecture service (i.e. either a streaming or VoD service), W_{L} the consumption of the accommodation of the students and $W_{\mathrm{D,on}}$ the consumption of the devices used to join the online lecture. Again, these contributions can be broken down further:

The lecture service contribution W_{LS} is composed by

$$W_{\mathrm{LS}}(n_{\mathrm{S}}) = n_{\mathrm{S}} t_{\mathrm{lec}} \cdot \begin{cases} P^{\mathrm{VoD}}_{\mathrm{access}} + P^{\mathrm{VoD}}_{\mathrm{router}} + P^{\mathrm{VoD}}_{\mathrm{core\ network}} + P^{\mathrm{VoD}}_{\mathrm{data\ center}}, \\ P^{\mathrm{Streaming}}_{\mathrm{access}} + P^{\mathrm{Streaming}}_{\mathrm{router}} + P^{\mathrm{VoD}}_{\mathrm{core\ network}}, \end{cases} \tag{6}$$

containing access, router and core network power, and in case of VoD services, also the data center power.

The energy consumption due to the accommodation of the students W_{L} is described by

$$W_{\mathrm{L}}(n_{\mathrm{S}}) = n_{\mathrm{S}} \cdot t_{\mathrm{lec}} \cdot n_{\mathrm{light}} \cdot P_{\mathrm{light}}, \tag{7}$$

considering the number of lights n_{light} with a power draw of P_{light} at the study area of the students.

Last but not least, the power consumption of the used electronic devices $W_{\mathrm{D,on}}$ is given analogously to eq. (4):

$$W_{\mathrm{D,off}} = t_{\mathrm{lec}} \sum_{n_{\mathrm{S}}} P_{\mathrm{D}}, \tag{8}$$

the main difference being that the summation runs over all students.

3.3 Hybrid lectures

Hybrid lectures are calculated as a combination of an on-site and an online lecture, whereby the consumption of each sub-lecture is calculated as described in section 3.1 and 3.2, respectively. This means that the total consumption of a hybrid lecture is given by

$$W_{\mathrm{hybrid}}(n_{\mathrm{S}}, n_{\mathrm{onsite}}) = W_{\mathrm{on\text{-}site}}(n_{\mathrm{onsite}}) + W_{\mathrm{online}}(n_{\mathrm{S}} - n_{\mathrm{onsite}}), \tag{9}$$

with n_{onsite} being the number of students joining the lecture on-site

4. Results

4.1 Consumption of the TUM Garching campus

In this section, the results obtained with the data gathered for TUM as described in section 2 are presented, using our calculator detailed in section 3. Here, only the Faculty of Mechanical Engineering is considered, since the most data is available for this faculty and we can thus rely on a better statistic for the sampling procedure. Our investigations found that using other faculties does not yield significantly different results, but is connected to much larger statistical uncertainties and will thus not be discussed further. Figure 3 shows the results obtained for both a hybrid-streaming and a hybrid-VoD (video-on-demand) lecture, either with 450 students (i.e. in cases where the lecture hall is at full capacity) or 30 students. Throughout this work, it is assumed that the duration of a lecture is 90 minutes. What immediately stands out is the fact that the total consumption is dominated by the transportation, and it is only in cases where very few students join on-site that it becomes negligible. This leads to the result that an on-site lecture is never the favored lecture mode from an energy consumption perspective, as the consumption of the transportation surpasses all other contributions by up to two orders of magnitude, based on the data collected in our survey. In contrast, when considering all contributions except transportation, a pure on-site lecture is favored. This means that the on-site lecture is made unfavorable purely by the contribution of the transportation.

Regarding all other contributions, most of them behave as expected and scale linearly with the number of students (e.g. the living costs or streaming/ VoD service) or are constant in case of the lecture hall. The only deviation from this behavior is in the case of the electronic devices, which is caused by the fact that students tend to use electronic devices in both online and on-site lectures, but to varying degrees (e.g. by connecting to a second monitor or using a desktop PC during online lectures). Nonetheless, the consumption caused by the device usage increases the more students join the lecture online and it becomes the dominating contribution for lectures where the majority joins online.

Furthermore, it should be pointed out that, in cases where the lecture hall is used (in a full on-site scenario), the consumption of the lecture hall is rather minor and is overshadowed by the consumption of the electronic devices. This drastically changes if the lecture hall is severely under-used (see the lower row of Figure 3). In such cases, the lecture hall is the driving factor of the on-site consumption, since it is designed for 450 students.

Last but not least, it should be highlighted that in our data, the VoD online lecture consumes more energy than a streamed online lecture, due to the storage of the videos in data centers. Yet, since the difference does not change the overall tendencies of the result, the focus will be on the streaming mode for the remainder of this section. The VoD lecture also seems to be less suited for a “simultaneous hybrid lecture” and is further complicated by the fact that a VoD might be watched several times, adding further uncertainties.

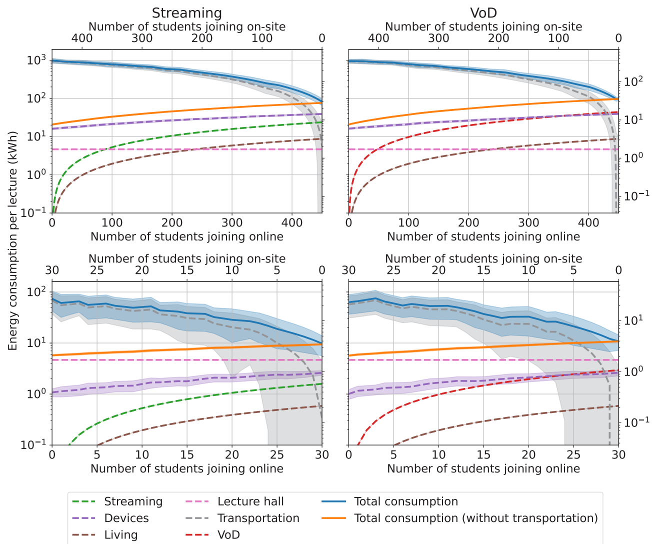

Figure 3: Results obtained with our TUM data. The upper row shows a hybrid-streaming and – VoD (video-on-demand) lecture with 450 students, the lower row the same scenarios with only 30 students. The shaded regions indicate the 1σ statistical uncertainty region originating from the sampling procedure described in section 3. The kinks in some of the curves are an artifact of the statistical sampling.

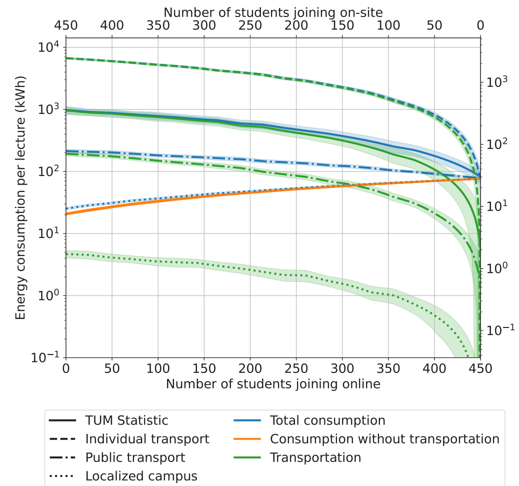

Figure 4: Comparison of different means of transport scenarios. The shown scenarios are either the means of travel as established by our survey (TUM statistic), all students going by car or motorcycle (Individual transport), all students not arriving by bike or on foot using public transport (Public transport) or 90% of students arriving by bike or on foot with the remaining 10% traveling 15 minutes by bus on average (Localized campus). The individual contributions to the total consumption are identical to Figure 3 and not shown for clarity. The shaded regions indicate the 1σ uncertainty region originating from the statistical sampling described in section 3.

4.2 Case studies based on the TUM data

In this section, several case studies are presented where specific areas of the TUM data are modified to illustrate the effect of changes of, e.g., the traveling behavior of students.

4.2.1 Individual transport vs. public transport vs. localized campus

The first case study focuses on the effect of different means of travel on the total consumption. Here, three different cases are compared to the original TUM data illustrated in Figure 3: The "**Individual transport**" scenario assumes that students would travel by car or motorcycle (equally split), whereby the travel time is randomly drawn from a normal distribution with a mean and standard deviation equal to the values of the car and motorcycle users from our survey. Similarly, in the "**Public transport**" scenario, all students not already arriving by using the subway or bus (or on foot/by bike), are now represented as using the subway with their travel time randomly drawn from a normal distribution around the travel time of the subway users from our survey. Lastly, a scenario is considered where all students live within walking or cycling distance of the campus, and only 10% of students are using the bus ("**Localized campus**"). Their travel time is normal distributed with a mean of 15 minutes and a standard deviation of 5 minutes.

The results of this case study are illustrated in Figure 4, together with our TUM data for comparison. It becomes immediately evident that individual transport is in no way a desirable outcome as it increases the energy consumption by another order of magnitude. In contrast, when students use public transport, this would drastically reduce the consumption, but not yet to a degree where on-site lectures consume less energy than online lectures. This is due to the rather long travel times found at TUM (see section 4.2.2 for more details). If now a campus is considered where most students can go to their lectures on foot or by bike, the transportation consumption becomes, as expected, small enough to be no longer a driving contribution, which leads to the fact that on-site lectures become the cheaper option. In this case, the total consumption is again dominated by electronic devices.

4.2.2 Influence of travel time

Following the insights gained in section 4.2, the influence of different travel times on the total consumption is investigated. Here, the case study is based on the “**Public transportation**” scenario from the previous section, i.e. all students using public transportation, in an effort to explore further options on how to make on-site lectures at TUM consume less energy. The travel time of all students using public transport is systematically decreased by replacing their travel time by a random time drawn from a normal distribution around 5, 10 or 20 minutes, with a standard deviation of 5 minutes for the mean of 5 minutes or 10 minutes for the other two cases. For comparison: the average travel time in the “**Public transportation**” scenario is around 49 minutes, which is roughly the same as for our TUM data with an average of around 52 minutes. The resulting consumptions are illustrated in Figure 5.

The takeaway from this study is that, in an effort to significantly reduce the contribution of the transportation in a TUM-like means of travel distribution, the travel time has to be cut down significantly to make an on-site lecture consume less energy than an online lecture. In our calculation, this would mean that students need to travel on average at most 5 minutes – even if exclusively using public transport –, which effectively means that the campus should be located, e.g., within only a few stations of the subway. Nonetheless, even for such reduced travel times and public transport only, the transportation consumption is still the dominating contribution for full on-site lectures.

4.2.3 Device usage and lectures per day

In the last case study, the influence of the device usage during on-site lectures and the effect of the number of lectures per day is investigated. Here, the “**Public transportation**” scenario from section 4.2 is again taken as a baseline, but the device usage is modified during on-site lectures, i.e. set to 0, down from the original 75%. This scenario is then further modified by increasing the lectures per day up from 2.7 (i.e. the value used in the previous sections) to 5 or 10. The results can be seen in Figure 6.

Although not using devices in on-site lectures drastically reduces the consumption before considering transportation, it has little effect on the total consumption. If students do, however, take more lectures (or, e.g., tutorials for that matter) per day, the contribution of the transportation to a single lecture can be again reduced. In our model, students would need to travel for around 10 lectures (15 h lectures non-stop!) to the campus, to effectively make the on-site lectures more favorable in terms of energy consumption than the online lectures. In summary,while not using electronic devices in lectures has little effect on the total consumption, traveling to the campus for as many lectures as possible can have a much more beneficial effect on the total consumption.

5. Discussion

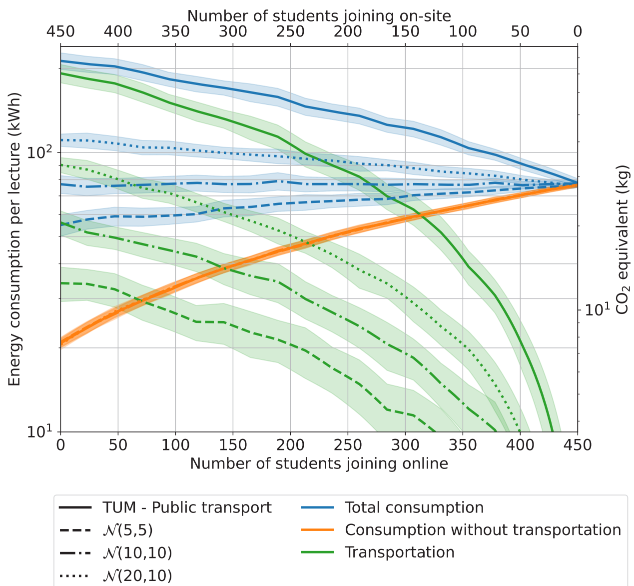

Figure 5: Comparison of different travel distances scenarios. The shown scenarios are based on the “Public transport” scenario shown in Figure 4. Here, this scenario has been modified by varying the average travel time of students using public transport, whereby the travel time is drawn from a normal distribution $\mathcal{N}(\mu,\sigma)$ with the indicated properties. The shaded regions indicate the 1σ uncertainty region originating from the statistical sampling described in section 3.

5.1 Student satisfaction and well-being

The last section of our survey assessed five more subjective changes in student life during the pandemic, namely in productivity, social life, liking of university, grades and mental health.

Productivity decreased in over half (52.3%) of people, stayed the same for around one quarter (22.3%) and increased for another quarter (25.4%), resulting in a slight decrease on average (Av 2.6, Med 2). This may be explained by more distractions in the home environment, such as electronic devices leading to procrastination, more free time and therefore less time sensitivity and possibly less accountability while working alone at home as compared to in groups with others.

Most students experienced a stark decrease in their social life during the pandemic, undoubtedly explained by the COVID-19 restrictions: almost three quarters (70.5%) of students stated that their social life got much worse or worse, while only 12.5% stated it improved (Av 2.2, Med 2).

When asked if they liked university more or less compared to before the pandemic, almost half (44.7%) chose “less” or “much less”; 37.5% said their feelings did not change, and only 17.9% declared liking it more. This slight decrease (Av 2.6, Med 3) could be explained by less interactive lecture formats, fewer internships and seminars and likely by less contact with other students, a crucial part of university life.

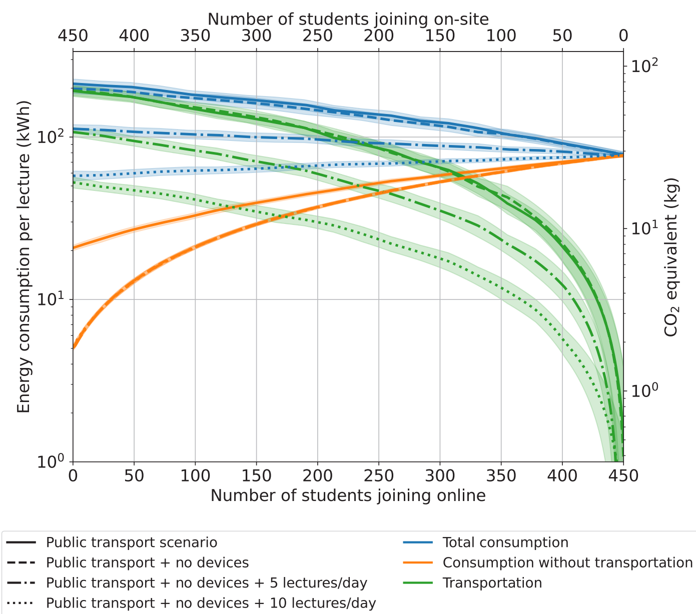

Figure 6: Investigation of different device usages and lectures per day. Here several scenarios are compared in which students do not use any electronic devices during on-site lectures with the “Public transportation” scenario from Figure 4. Additionally, in two scenarios, the lectures per day are increased compared to the value established by our survey. The shaded regions indicate the 1σ uncertainty region originating from the statistical sampling described in section 3.

Interestingly, the grades of most (53.6%) students stayed the same (Av 3, Med 3). Only very few got much better or much worse grades. This lack of change, despite a decreased productivity and liking of university, might be explained by two factors: more time to study – there was no commuting and less social life – and possibly easier exams, as many lecturers were aware of the difficult situation and were trying to not make student life even harder. Finally, and as one would expect, the mental health of students got worse during the pandemic (Av 2.5, Med. 2). While around one third (35.7%) of students saw no change in their mental health, over half (52.2%) of students saw a decline, with 38.8% and 13.4% stating that it got worse or much worse, respectively. Only 12.1% experienced their mental health improving. Although this might well be linked to the university experience of our participants, the general context has to be considered here. Undoubtedly, these unprecedented and highly challenging times have had a negative impact on students' mental health as well.

To further analyze the data, we looked into the interrelationships between different answers and created a correlation matrix (see Figure 7) based on Peason's correlation coefficient (Pearson 1895) (blue = negative correlation, red = positive correlation).

It is clear that all five of these subjective changes (5 SC) are strongly positively correlated, meaning that students generally either suffered in all areas or weren't so affected in all of them. For example, those who liked university less also saw a greater decline in productivity, or those whose social life didn't decrease also suffered less mentally.

Positive correlations were found for age and the 5 SC, meaning younger students suffered more from the changed conditions in the pandemic. This might be due to the fact that older students already had ties to teachers and fellow students, while younger ones often only started university in COVID-times and therefore didn't have those connections. No strong correlations were found between the 5 SG and gender, and perhaps more interestingly, between the 5 SC and the students' living situation. One might have expected students living alone to be more affected than those living with friends or family, but that didn't seem to be the case. Those living alone did seem to require fewer lectures per day in order to make it seem worth the travel to university.

Perhaps not surprisingly, students with a lower satisfaction and well-being during the pandemic tended to wish for more on-site lectures in the future, and seemed to think they required less energy as compared to online lectures. Whether the perceived lower energy cost led to the preference for on-site lectures, or this preference biased the energy estimation, we cannot say.

Besides general limitations of the study, this section is especially affected by the fact that many participants were not yet students at the beginning of the pandemic, therefore possibly distorting the changes in these factors. Furthermore, as mentioned above, these parameters are also more subjective than others and therefore have to be handled more carefully.

5.2 Economic aspects

To assess the advantages and disadvantages of online lectures for students, not only the subjective student satisfaction and mental health should be considered besides the energy consumption of lectures. The person and/or institution responsible for covering the expenses linked to the different lecture formats must also be taken into consideration. To do so, the different sources of such expenses must be delimited. Here, three main sources can be considered: material, energy consumption at the lecture site, and transportation.

Material, as a source of expenses, refers to the materials needed during lectures. While, for on-site lectures, only a notebook, a pen, and perhaps a lecture script are needed, an electronic device belongs to the minimum required for online lectures. Thus, only regarding the unavoidable materials, it is evident that, with electronic devices being more expensive than the non-electronic goods, students have to bear higher expenses for online lectures. Further, considering that the majority of students also use electronic devices during on-site lectures (62.1% always, 15.2% sometimes), the existence of these avoidable devices in on-site lectures must also be taken into consideration. However, even considering this existence, students still have higher expenses during online lectures.

Besides causing an increase from 62.1 to 100% in the percentage of students who always use electronic devices during their lectures, a switch from on-site to online lectures is also responsible for the addition of an additional screen to the electronic devices used (for 34.4% of the surveyed students).

As the second source of expenses considered, the energy consumption at the lecture site refers to the infrastructure expenses, such as lighting, and the expenses connected to the use of electronic devices. The infrastructure expenses are covered by the university during on-site lectures and by the students or their families during online lectures. Thus, through the shift from on-site to online lectures, the infrastructure expenses are taken away from the university. Since the percentage of students living with their families decreased during the pandemic (from 43.8 to 30.4%), it can be assumed that the infrastructure expenses are mostly directly transferred from the university to the students. Regarding the expenses connected to the use of electronic devices, three points must be considered. First, since the mobile electronic devices can be charged during on-site lectures, the costs referring to the energy consumed for charging the personal electronic devices do not only rely on the students. During online lectures, however, these costs rely on the students, hence increasing their personal expenses at home. Second, as previously discussed, online lectures are responsible for an increase in the number of electronic devices used, thus also increasing the energy consumed in the students' homes. Third, during online lectures, more powerful devices such as desktop-PCs also come into use, which also increase the energy consumed at home. Consequently, not only are the expenses regarding the infrastructure and the powering of devices shifted from the university to the students during online lectures, but the expenses regarding the powering of devices are also increased in this lecture format.

The last source of expenses considered, the transportation, is less straight-forward than the sources previously discussed. Since the most used means of transport among students refer to local public transport, the following discussion is based on this type of transportation. In Munich, university students, including those of TUM, have the opportunity to buy a ticket for over 200 Euros, with which

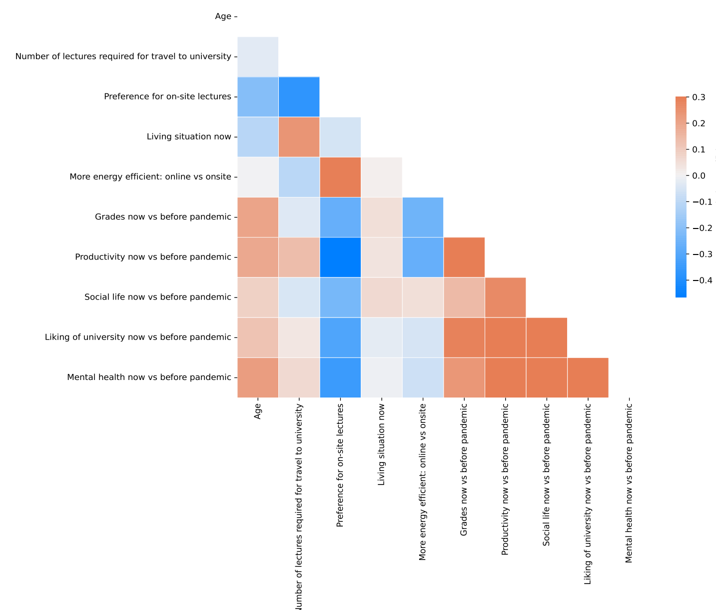

Figure 7: Correlation heatmap of selected survey results, as measured by Peason's correlation coefficient. Positive correlations in red, negative correlations in blue. Darker colors indicate a stronger correlation.

they can travel freely with local public transport during the current semester[3]. In a scenario in which the lectures happen solely online, one can argue that this ticket is not necessary, hence helping students save over 200 Euros per semester. However, in a non-pandemic state, it most likely would still be interesting to buy such a ticket from a financial point of view since traveling to and from social events, for instance, would still be needed. Hence, with this assumption, there would not be a saving from on-site to online lectures. Since the willingness to buy the mentioned ticket was not a question included in the conducted survey, this assumption cannot be confirmed.

3 https://www.mvv-muenchen.de/en/tickets-and-fares/frequent-travellers/mvv-semesterticket/index.html, last accessed 12.03.2022

In conclusion, even though online lectures are responsible for a lower energy consumption, several student expenses are higher in this lecture format. Besides the greater need for (more) electronic devices, online lectures are responsible for the use of electronic devices with more power and for shifting the infrastructure expenses from the university to the students. From a transportation point of view, the effect of the lecture format on the adherence to the explained semester ticket is unclear. To assess this adherence and, with that, the effect of the lecture format on the transportation expenses, an extra survey on this topic would need to be conducted.

5.3 Discussion of the case studies

Transportation appears to be the major contributing part to the energy consumption of on-site lectures in the case of TUM Garching, making on-site lectures in any case worse in comparison to online lectures in terms of energy consumption. The reasons for that can be found in the location of the campus: TUM Garching is situated around 13 km away from the city center of Munich (see Figure 2 SI). In addition, only a few dormitories are available in its proximity. The high living costs in Munich lead to some students not being able to live in the city but rather hvaing to commute to the university from the suburbs. Combined, these factors result in long travel distances, with the commuting time of the average student being around 50 minutes. Furthermore, even though only 12% of travel is done individually, its impact on the total energy consumption is vastly higher (car: ~22 fold; motorbike: ~13 fold consumption as compared to public transport per person). If all students came individually, this would even lead to the energy consumption being one order of magnitude higher.

However, a campus located somewhere near the city center with a shorter travel time for the students still does not make a big difference – in fact, the travel time needs to be decreased down to 5 minutes with the students using exclusively public transport for the on-site lecture to be more favorable than the online lecture in terms of energy consumption. Alternatively, a “localized campus” similar to American campuses, with a vast majority arriving by foot or bike, and the rest by bus, would be a scenario where the same result can be achieved.

With this in mind, a realistic, energy saving mode of a lecture suitable for TUM Garching could involve a hybrid format where the students with a long travel time join the lecture online whereas students living in close proximity, i.e. up to 10 minutes of public transport, join on-site.

Another approach to minimize the energy consumption is to have more lectures scheduled per day and thus fewer days at university per week, to make the most use of the energy spent for transportation to the campus. While it is of course unrealistic to have 10 lectures a day, as calculated in section 4.2.3, 5 to 6 lectures should be possible to attend. In combination with a shorter travel time, this is also a doable way of reducing the consumed energy per on-site lecture.

Of course, both strategies require the appropriate lecture hall sizes for each course at close to maximum capacity in order to make the most of the constant energy consumption of the facility. Also, the students can actively contribute to reduce the consumed energy per lecture. If they only have one lecture scheduled on a day, it makes sense to join the lecture online – if offered – to save energy.

The university, in return, can advise the lecturers to offer a livestream of their lecture and promote public transportation, e.g. by building the respective infrastructure. In the long term, the construction of dormitories in proximity to the campus is one of the most effective ways to minimize the energy consumption of academic teaching.

5.4 Validity and transferability of the results

Even though solid research was conducted to gather the necessary data to use in the developed calculator, two main sources of error should be considered. First, only 224 TUM students answered the conducted survey. Considering that TUM had a total of 48296 enrolled students in the semester during which the survey was conducted[4], the number of answers might not be fully representative for the en-

4 https://www.tum.de/en/about-tum/our-university/facts-and-figures, last accessed 12.03.2022

tirety of TUM students. Second, even though the living situation and the age of the electronic devices of students were inquired into within the conducted survey, this data was not included in the calculations presented in section 4. The influence of the living situation was not used due to missing data on the energy consumption of different student accommodations found in the Studentenwerk München. The influence of the device age was left out since it causes two opposite effects. On one hand, older devices tend to be less energy-efficient than newer ones. On the other hand, with technological advances, newer devices often have more powerful components, such as video cards. Thus, the effect of age on the power of an electronic device cannot be clearly quantified. The missing considerations of the living situation and the age of the electronic devices, however, should not have a significant influence on the final results. Since the energy consumption of transportation is up to two orders of magnitude higher than the energy consumption of other consumption sources (see section 4.1), small changes in the energy consumption of the living situation infrastructure and of the electronic devices would not affect the shown trend that on-site lectures consume more energy than online lectures. Due to the magnitude of the transportation, a study with more participants would also hardly change this trend since, as described in section 5.3, the location of the TUM campus in Garching is prone to cause high commuting rates. Hence, even though there is a certain margin of error to be considered, the general trend found in this study should still be seen as valid.

Besides analyzing whether the results of the conducted study are valid for TUM and, more specifically, to its campus in Garching, the transferability of such results to other universities should also be investigated. Due to the long commuting distances to the studied campus, only other universities with long travel distances can be directly compared to the TUM campus in Garching. As seen in Section 4.2.2, the travel time can play a significant role when it comes to reducing the energy consumption of on-site lectures. Further, since the majority of students commute to the university using local public transport, the city of the university to be compared with TUM must have a solid public transportation infrastructure. At the same time, however, it should be considered that a percentage of TUM students also commute to the university by car. Section 4.2 shows that there is a notable difference between the TUM reality and a scenario in which students would only commute using public transport. This difference should also be noted when transferring the results to other universities. Further, especially considering the influence of individual transportation, which has its energy consumption calculated based on the emission of CO_2-equivalents (See Section 2), the country of the analyzed university must have a power grid similar to the one found in Germany. Lastly, regarding the use of devices and the number of lectures per day, which are thematized in Section 4.2.3, the transferability of the TUM results to other universities can be directly assured. First, it was shown that the number (and type) of devices used barely influences the energy consumption of on-site lectures when the TUM-like transportation is taken into consideration. Second, no matter what university, one can imagine that students would hardly want to attend more than 5 lectures (7.5 hours) per day. Consequently, the energy consumption of on-site lectures would still be higher than that of online lectures for any analyzed university that is similar to the TUM campus in Garching in the other aspects discussed.

Based on the conducted case studies (Section 4.2), universities with other realities, e.g. with a localized campus, can also analyze the energy consumption trends of their lectures and follow the general suggestions made in Section 5.3 on how to conduct energy efficient lectures.

6. Conclusion and outlook

In this study, the energy consumption of online and on-site lectures is compared. To the best of our knowledge, this is the first study of its kind.

The used data is based on literature and a performed survey. An online calculator is created for the estimations in this study but is usable for other universities as well. Uncertainties in the results remain due to assumptions based on the available data, hence only trends and no absolute numbers are discussed in the study.

The lecture site is the TUM Garching campus, which is located somewhat outside of the city. Thus, the results are valid for remote campuses, but the described scenarios are also applicable for local campuses.

On-site lectures consume up to 2 orders of magnitude more energy than digital formats, making any combination of both always more energy intensive than purely online lectures. Transportation is the highest energy consuming factor. For more local campuses, i.e. with a decreased requirement of transportation, hybrid or purely on-site lectures can become more favorable in terms of energy consumption, especially if several on-site lectures are attended in one day.

Approaches towards more energy efficient lecture formats include the suggestion for students to join online if they do not live in close proximity to the university, to concentrate the lectures on as few days as possible, to operate the lecture halls at maximum capacity and to provide student housing in the surroundings of the university in the long term. However, in the discussion of efficient lecture formats, the cost factor for students and student satisfaction have to be considered.

The discussed trends in this study might give certain hints on the energy consumption in similar cases, e.g. when comparing online meetings versus on-site meetings. Here, the same factors will make one format more favorable in terms of energy.

In future studies, the energy consumption of online and on-site lectures will be compared with the focus on heating and air conditioning. It is unclear to what extent individual heating and air conditioning of the student apartments might increase the energy consumption of online lectures, making them unfavorable in cold or hot seasons.

Data availability statement

The raw data collected on the lecture hall, means of transportation and living situations of students is available in the supplementary information[5]. The survey data, both in a raw and post-processed format will be made available upon reasonable request.

5 https://docs.google.com/document/d/1_MO0ayQa8yu1KAbHsCVwT2SGo8Jh4FO7Ub8xOteZEpQ/edit?usp=sharing

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Check out our supplementary information (SI)!

Try our calculator yourself!

Self-reflection

Our TUM: Junge Akademie journey started with the first Zoom meeting held in November 2020.

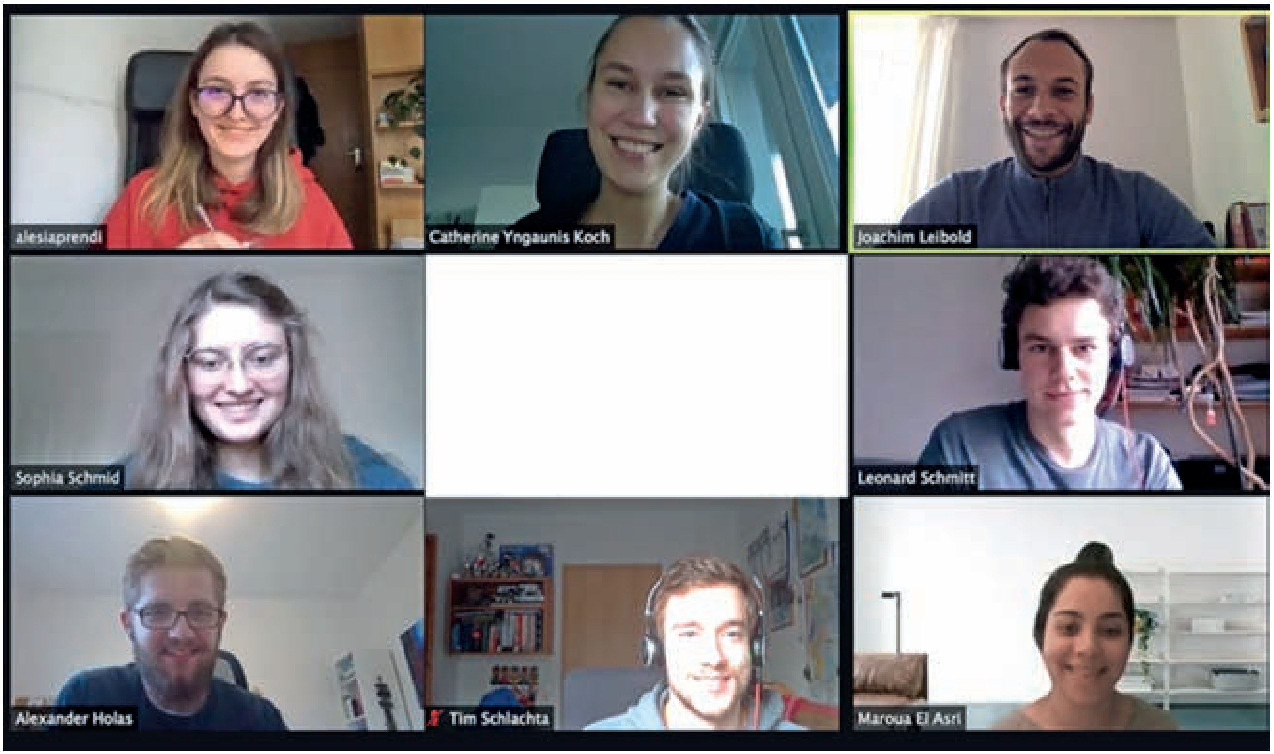
A team of eight students with a multi-disciplinary academic background and diverse cultural upbringing came together under the name of Team Climate. Most team members were decisive about joining the team from the start, even though we all are from different fields, including chemistry, physics, medicine, architecture, sustainability, and politics. Regardless of this diversity, the theme of climate was intriguing to all of us. Starting from the broad topic of climate, many brainstorming and discussion sessions took place before we decided on the impact of energy consumption of online and on-site classes as our chosen research topic. The idea stemmed from the impact of COVID-19 on our university life and from the new way of conducting courses. The main questions we wanted to tackle were whether studying from home helps reduce the energy consumption and carbon footprint of students and what is the optimal combination between online and on-site lectures to minimize the overall energy consumption of TUM lectures. Thus, our developed research question was: to what extent can the combination of online and on-site lectures minimize the energy consumption of academic education? Having developed a calculator tool and finalized our research, our current purpose is to provide TUM with our results, hence helping inform its decision on which lecture type to favor in terms of energy efficiency, especially during this critical phase of transitioning towards going back to “normal.” Further, an option in our developed calculator tool allows students to calculate their own energy consumption.

In order to further develop the topic, we had brainstorming and discussion rounds with our supervisors when we reached important milestones and with mentors during the seminar weekends organized by the TUMJA office. These talks were very helpful to the team in narrowing down the topic and precisely defining our research question. After that, we divided the team into three subgroups: survey, data collection and calculator. This division of tasks proved productive. First, it allowed the sub-teams to focus on one direction of the topic. Second, it made the discussions and decisions to be taken within the sub-team easier, given the smaller number of team members. Hence, it was more effective to work in small subgroups and check in with the entire team when a subgroup reached an important milestone than to conduct long discussions in our eight-students team.

During our TUMJA journey, we also faced some challenges. Given the size of the team and the different backgrounds of its team members, our brainstorming discussions were very interesting but also intense and time consuming. Thus, we came up with a meeting structure where we took turns to be the moderator, responsible for keeping the discussions from straying off topic, and a minute-taker to keep track of our decisions during the meeting. Further, we tried to limit our meetings to one hour and have a small vote at the end to assess the mood and productivity of the team during the meeting. This structure proved very helpful for us to keep on track and follow up with our planned agenda. Additionally, it gave the opportunity to each team member to experience running a meeting or taking minutes of meetings– certainly great skills to learn before beginning our careers.

In addition, the COVID-19 pandemic was a challenge for us, as it did not allow us to experience the TUM: Junge Akademie at its fullest. Previous classes had the opportunity to have regular face-to-face meetings and bonding activities so the bond among them was definitely stronger than in our class 2021. However, we tried to make the best of it. We planned some in-person meetups when the COVID situation permitted it, such as going for dinner together or hanging out over ice cream.

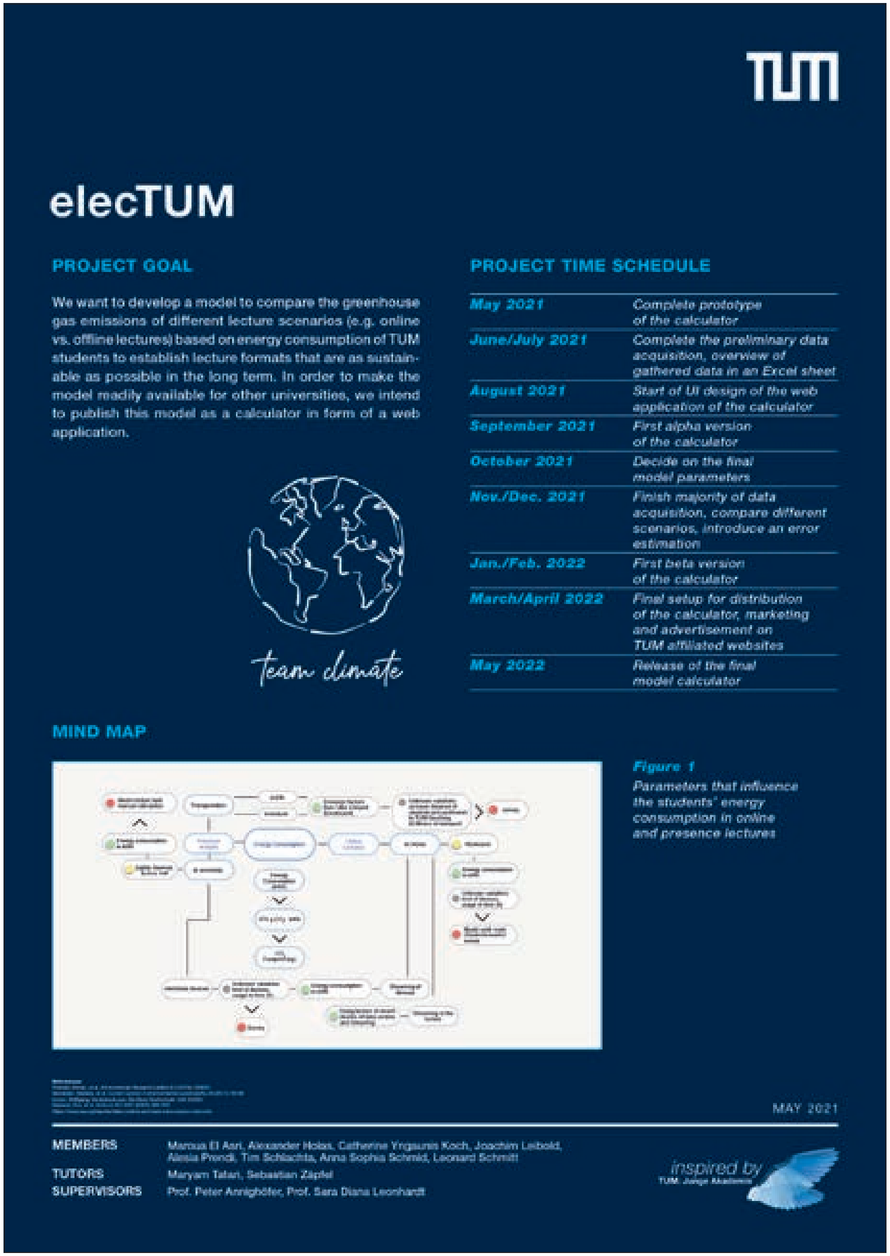
TUMJA is an exciting and a challenging experience at the same time. Given the freedom we had as a team, with the opportunity to choose and implement our own project, conflicts were bound to arise due to the substantial differences among team members. Through our experience as a team, we learned that the most fruitful way to deal with such conflicts is, firstly, to openly bring up and discuss issues with the whole team and the tutors as early as possible, as this avoids making the issue personal and helps with de-escalating the problem. Second, as we are in a volunteering environment, communicating one's expectations and degree of involvement is key to enable the other team members to manage their expectations and own workload. Along with this, it is very important to keep



a respective tone at all times in order to avoid escalating the issue and making the matter personal. Lastly, the tutors and the TUMJA office are always available to help and provide constructive advice when they know about problems in the team early on.

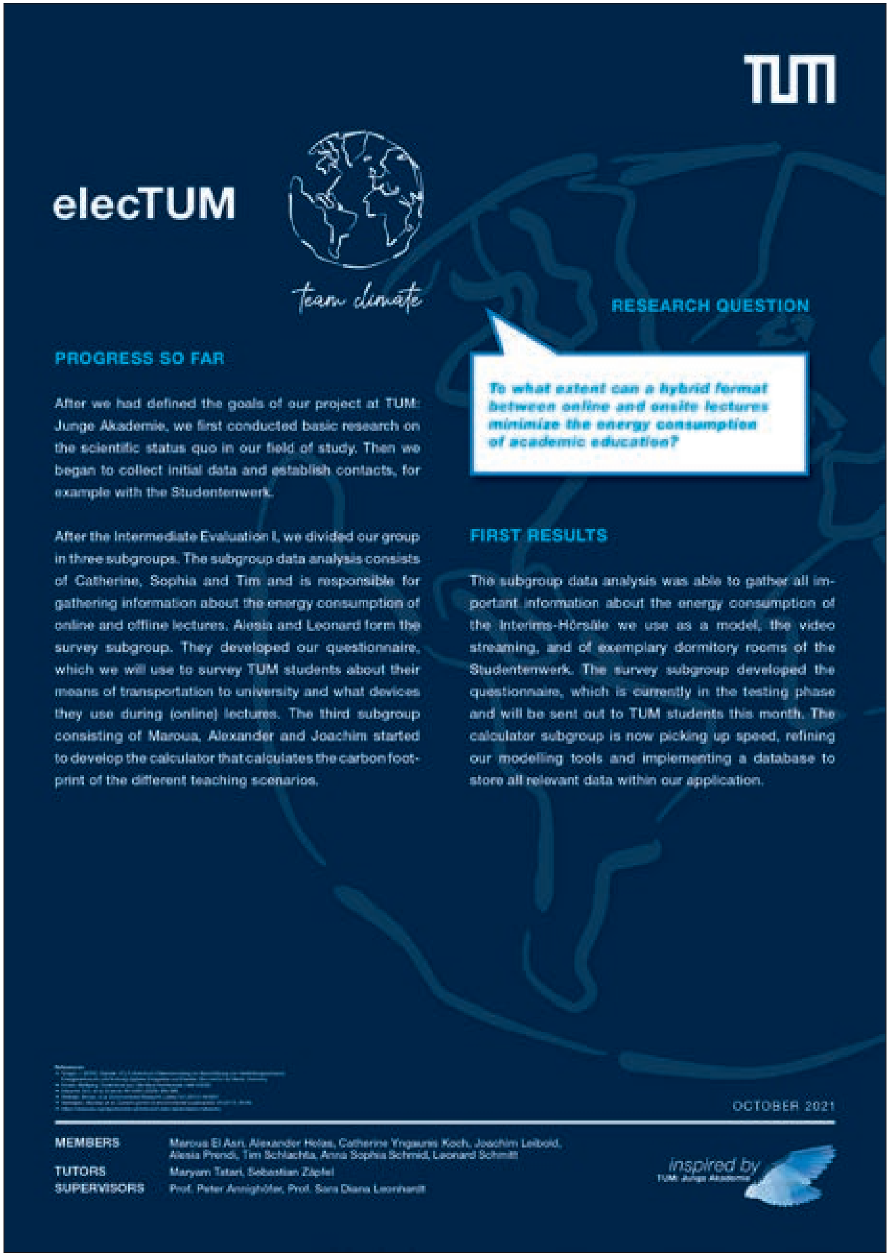
Finally, we are grateful to our supervisors Prof. Dr. Sara Leonhardt and Prof. Dr. Peter Annighöfer for the great discussions, their feedback and for always helping us when we had any questions or needed contacts, for example to distribute our survey. We also want to thank Maryam Tatari and Sebastian Zäpfel, our tutors, who followed up with us since day one of our project and guided us when we needed it, especially towards the end of our project. We would like to thank our external collaborators and supporters who helped us with brainstorming in an early stage of our project. Further, we would like to thank the Studentenwerk München and the facility management of the TUM Garching Campus for providing us with energy consumption related data of student dorms and lecture halls, respectively. Similarly, we appreciate the Sustainability Office at TUM, which provided valuable feedback about our project and the different TUM student organizations that helped us with distributing our survey. Also, we would like to express our sincere thanks to Peter Finger and the whole TUMJA team for their great commitment, which helped us in every situation to realize our project.

Team elecTUM



POSTER 1:

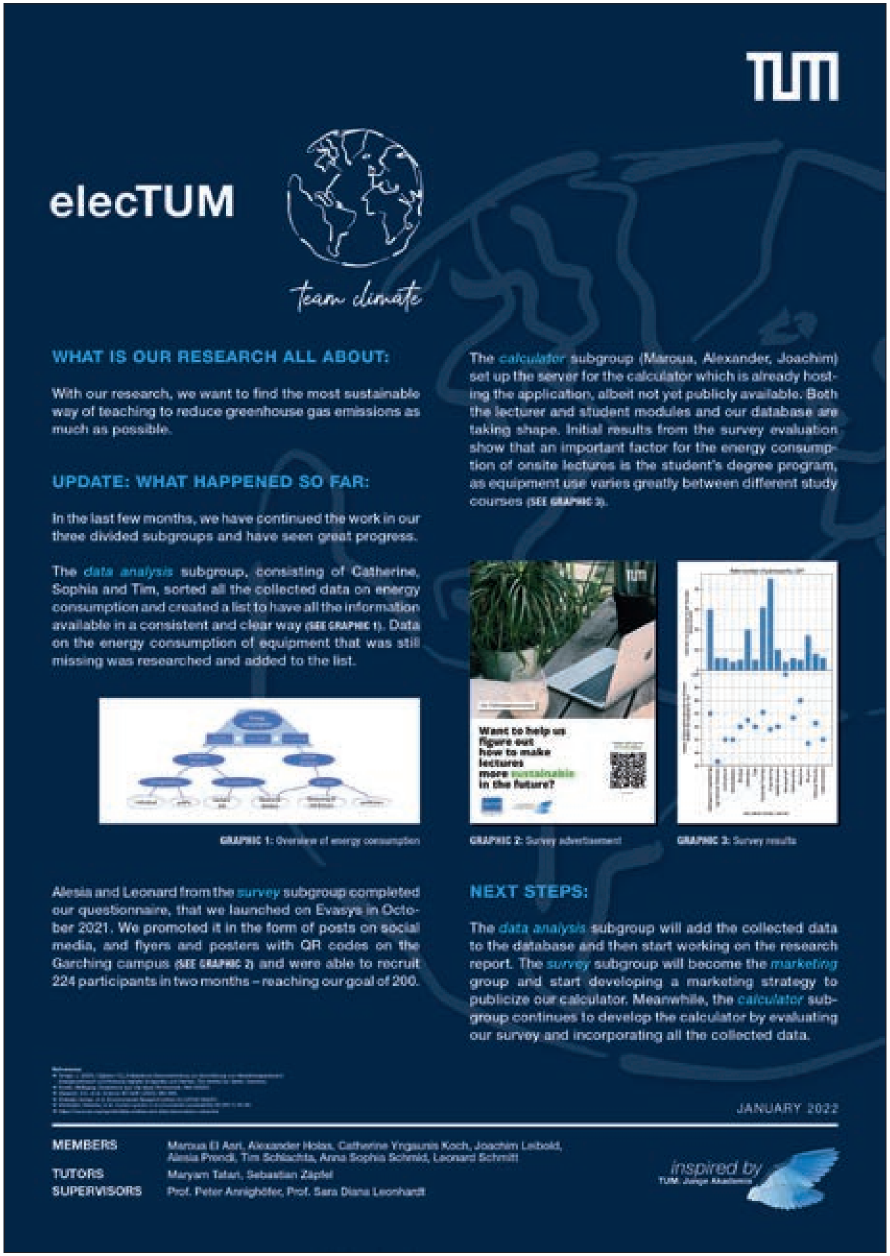
During our first scholarship months, we had several project management workshops in which we focused on defining a project goal and our time schedule. For the project goal, we first had to narrow down the topic of "climate" to a concrete subject that we could investigate. After long discussions, we decided to use the energy consumption of lectures to measure the impact of TUM students –and TUM in general – on the climate. Further, since we wanted to develop a project that would impact other universities as well, we included developing a web-based calculator in our project goal. This calculator could then be used by other universities and their students to assess the energy consumption of their own lectures. For the time schedule, we mainly focused on the steps that had to be completed regarding the development of the calculator and the acquisition of data, which would be inserted in the calculator for TUM-specific calculations. Lastly, after having achieved these project management milestones, we started brainstorming on the aspects that contribute to the energy consumption of students during online and/or in-person lectures. ■



POSTER 2:

During the time between posters #1 and #2, we continued working on our project management. To be more effective, we decided to divide our group into three sub-teams. The first was responsible for collecting necessary data for the TUM-specific calculations, such as the energy consumption of public transportation in Munich. The second was in charge of creating the survey, designed for collecting TUM-specific data on the students' behavior during lectures. Finally, the third focused on developing the web-based calculator. From this sub-team configuration, the first results started to emerge during this time: subgroup one was able to collect information regarding the energy consumption of a typical lecture hall at TUM and a typical student dorm from the Studentenwerk; the second subgroup completed a preliminary version of the survey; and sub-team three started implementing a database that would be later integrated in the web-based calculator.

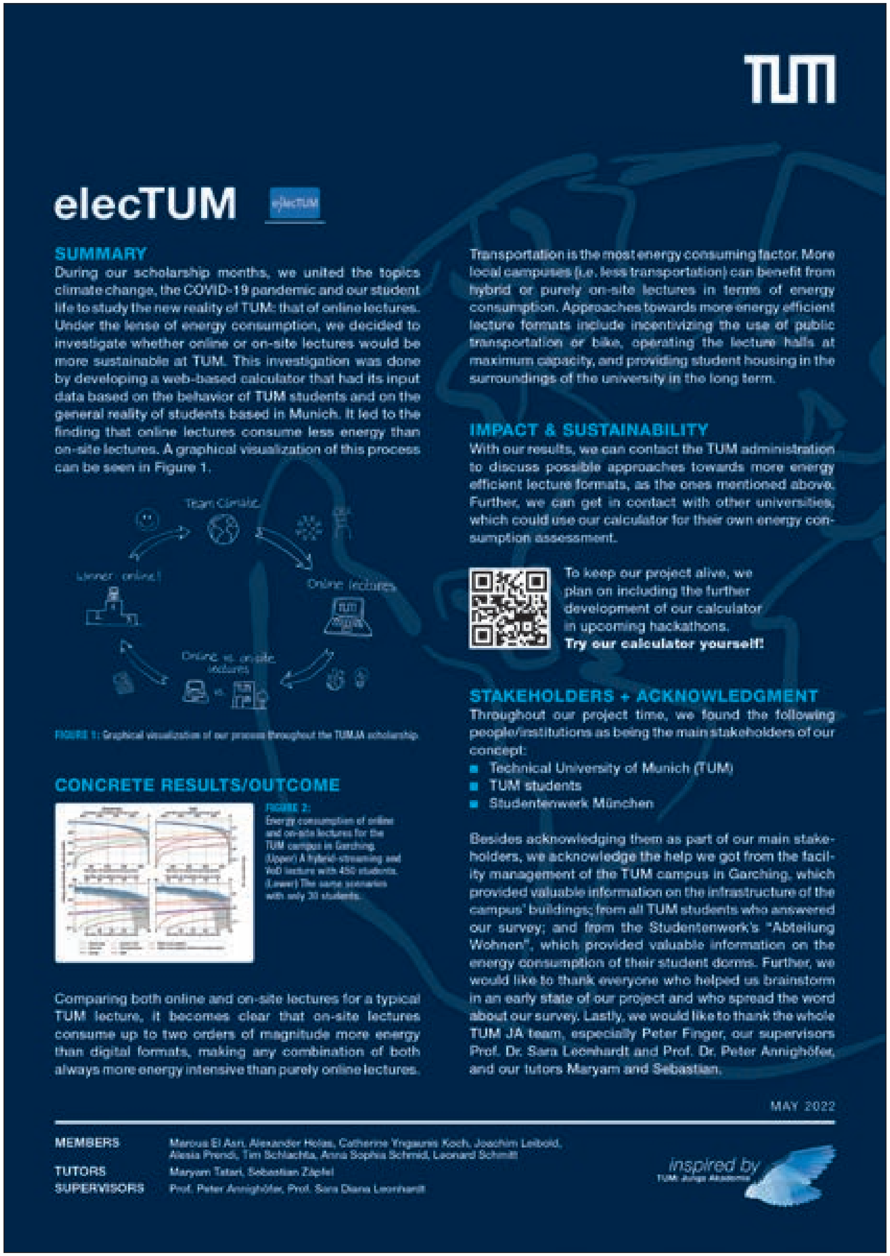
Shifting from project management and our general progress, we also developed our research question during the time between posters #1 and #2. With the question "To what extent can a hybrid format between online and on-site lectures minimize the energy consumption of academic education?", we were able to narrow down the climate question to energy consumption, to include all forms of academic education, and to ask about the possibility of having a hybrid lecture format as the optimum scenario.



POSTER 3:

Between posters #2 and #3, we had our most effective months. The first subgroup was able to complete its data collection and organized the found data in an Excel spreadsheet. The second subgroup successfully launched the survey, which was answered by 224 TUM students! Lastly, the third subgroup set up the server for the web-based calculator. Having completed these essential steps, we had our last tasks clearly set for the upcoming months: the first subgroup would include all collected data in the database developed by the calculator subgroup; the survey team would become the “marketing team”, responsible for making our project and calculator known at TUM and for designing the website; and the last subgroup would finish the development of the calculator and include the collected data (from the other two subgroups) in it.

POSTER 4:



TUM

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SUMMARY

During our scholarship months, we united the topics climate change, the COVID-19 pandemic and our student life to study the new reality of TUM: that of online lectures. Under the lense of energy consumption, we decided to investigate whether online or on-site lectures would be more sustainable at TUM. This investigation was done by developing a web-based calculator that had its input data based on the behavior of TUM students and on the general reality of students based in Munich. It led to the finding that online lectures consume less energy than on-site lectures. A graphical visualization of this process can be seen in Figure 1.

Team Climate
Online lectures
Online vs. on-site lectures
Winner: online!

FIGURE 1: Graphical visualization of our process throughout the TUMJA scholarship.

CONCRETE RESULTS/OUTCOME

FIGURE 2: Energy consumption of online and on-site lectures for the TUM campus in Garching. (Upper) A hybrid-streaming and VoD lecture with 450 students. (Lower) The same scenarios with only 30 students.

Comparing both online and on-site lectures for a typical TUM lecture, it becomes clear that on-site lectures consume up to two orders of magnitude more energy than digital formats, making any combination of both always more energy intensive than purely online lectures.

Transportation is the most energy consuming factor. More local campuses (i.e. less transportation) can benefit from hybrid or purely on-site lectures in terms of energy consumption. Approaches towards more energy efficient lecture formats include incentivizing the use of public transportation or bike, operating the lecture halls at maximum capacity, and providing student housing in the surroundings of the university in the long term.

IMPACT & SUSTAINABILITY

With our results, we can contact the TUM administration to discuss possible approaches towards more energy efficient lecture formats, as the ones mentioned above. Further, we can get in contact with other universities, which could use our calculator for their own energy consumption assessment.

To keep our project alive, we plan on including the further development of our calculator in upcoming hackathons.
Try our calculator yourself!

STAKEHOLDERS + ACKNOWLEDGMENT

Throughout our project time, we found the following people/institutions as being the main stakeholders of our concept:

- Technical University of Munich (TUM)
- TUM students
- Studentenwerk München

Besides acknowledging them as part of our main stakeholders, we acknowledge the help we got from the facility management of the TUM campus in Garching, which provided valuable information on the infrastructure of the campus' buildings; from all TUM students who answered our survey; and from the Studentenwerk's "Abteilung Wohnen", which provided valuable information on the energy consumption of their student dorms. Further, we would like to thank everyone who helped us brainstorm in an early state of our project and who spread the word about our survey. Lastly, we would like to thank the whole TUM JA team, especially Peter Finger, our supervisors Prof. Dr. Sara Leonhardt and Prof. Dr. Peter Annighöfer, and our tutors Maryam and Sebastian.

MAY 2022

MEMBERS Maroua El Asri, Alexander Holas, Catherine Yngaunis Koch, Joachim Leibold, Alesia Prendi, Tim Schlachta, Anna Sophia Schmid, Leonard Schmitt
TUTORS Maryam Tatari, Sebastian Zäpfel
SUPERVISORS Prof. Peter Annighöfer, Prof. Sara Diana Leonhardt

inspired by TUM: Junge Akademie

After poster #3, in the final phase of our project, we included all collected data in our database, completed the development of our calculator, and conducted all calculations needed to answer our question on the energy consumption of lectures. After conducting such calculations, we came to the conclusion that, for the TUM reality, online lectures consume significantly less energy than on-site lectures. Now that we have these results, we plan on approaching the TUM administration to discuss possible ways of reducing the energy consumption of TUM students with regards to their lecture's formats. Further, to keep our project alive, in the last months, we have assessed different possibilities of expanding our calculator. For instance, we were already in touch with the organizers of the EuroTeQaThon and those of the TUMJA Science Hack regarding the possibility of including our calculator as a challenge in their hackathons.