

Actively supporting K-12 Education from University Academy Programs

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Abstract—This paper features a model for promoting Science, Technology, Engineering, and Mathematics (STEM) in the K-12 education level by developing teaching platforms together with university students. Usually, technical universities develop simulators and technologies as part of academic plans and research projects with students. For instance, in sessions of a university semester project, students often develop technical solutions useful for later use to promote STEM topics. We document experiences at TU Berlin where bachelor students developed a simulator using a drone for measuring CO₂ levels in the atmosphere. The topic was challenging enough to fulfill the research requirements at the university; at the same time, the resulting code provided the material to prepare teaching activities at the K-12 level. Using the publicly accessible code, we also elaborate on lesson plans and activities to apply this specific example at the K-12 level.

I. INTRODUCTION

Promoting Science, Technology, Engineering, and Mathematics (STEM) at the K-12 levels implicitly extends possibilities to access universities and pursue technical careers. In Germany, the average population with tertiary education level is less than the average in the European Union (35.7 % to 41.2 % for 2021) [1]. Furthermore, a gender gap is evident among students and staff members at technical universities. For instance, at TU Berlin, only one-third of students are female (33–34 %) [2] and among professors it is only one-fifth (20–21 %) [3]. Addressing these issues demands motivating young people, and regardless the gender, to access technical careers, where the conception of broader educational actions at K-12 is of utmost importance.

Examples with supporting materials for instructors are given in the IEEE Try-Engineering portal [4]. There are projects implemented in the Minecraft game where students have to compute the volume, area, and perimeters of geometric figures while coding [5]. As another example, the Made with Code project launched by Google introduces various computer science (CS) concepts with visual programming tools and for various educational levels at K-12 [6]. Furthermore, using the Tinkercad app, students can also design 3D environments while coding [7], in this way promoting the learning of CS topics.

Various research studies report solutions and methodologies to promote CS topics at K-12 [8]. A most popular procedure is project-based learning, where students learn computing to solve a problem in a team project. Examples integrate CS with physics [9] or employ demos with electronic components to raise the interest in programming [10].

Instructors may conduct projects and ease the comprehension of programming using several methodologies. For instance, in

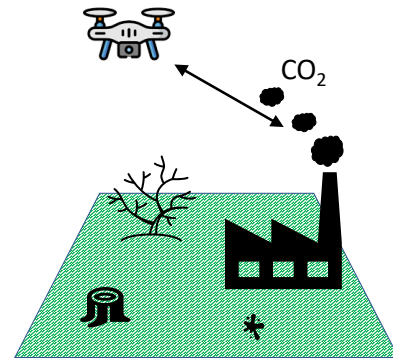


Fig. 1: Scenario for the proposed project at K-12 level.

the “use-create-modify” approach, students receive a portion of codes and are asked to complete, modify, or extend them [11]. This procedure also allows graduating complexity according to the school level. Another strategy is to use the “in-time” pedagogy, where concepts are presented following the student demands [12]. Additionally, teaching practice may ease the understanding of topics by implementing learning transitions from minor to more complex tasks [13]. It is reported that asking students to solve more accessible issues and repeat the same activity with more complex ones results in a deeper understanding of programming concepts [13].

The above examples conceive of implementing various tools in template codes, graphical user interfaces, or hardware prototypes. However, we highlight that these are tools commonly produced by master’s or bachelor’s students at technical universities as part of semester projects or final grade evaluations. In this regard, there are plenty of means at technical Universities to conceive platforms that later support K-12 teaching programs. When properly articulating academic programs at universities, the students’ work may be guided to develop technical platforms, about which instructors later design K-12 activities.

In this paper we document the experience in the conception of materials for the K-12 academic level, those conceived as part of student semester projects at university. This is addressed in the subject “Research Project Network Technologies” at the School of Electrical Engineering and Computer Science at TU Berlin. Bachelor students implement programmable tools fulfilling the learning outcomes at the university level, and at the same time, they become part of social intentions to

boost STEM.

Specifically, we target the climate change topic and the impact of CO₂ emissions, as depicted in Fig. 1. This topic also allows the introduction of climate-friendly technologies and the applicability of CS in support of mitigating the climate crisis. Following the tradition of Charles Lowe [14], we devise a drone surveillance platform in MATLAB at the university, intending to measure the CO₂ levels in the atmosphere (cf. Section II). The platform allows simulating a flying drone displaying its trajectory in 3D plots.

We also design some activities for K-12 level (class in the range 9–12 grade) through this platform, as illustrated in Section III. We conceive for K-12 students a project where they have to localize the source of CO₂ emissions based on measurements from the flying drone. Students are exposed to basics in mathematics and computing when programming the estimation of the emission source. They are guided to use Cartesian coordinates, as well as the law of diffusion to explain and understand the CO₂ emission process.

II. PROJECT CONCEPTION WITH UNIVERSITY STUDENTS

The student semester project at TU Berlin is a class for bachelor and master students typically comprising 6 credit points, i.e., a 150 to 180 hour workload per semester. Each semester, a number of different projects are offered and students are assigned a project in small groups (typically 3 to 5 people) according to their preferences.

The task of this particular project was motivated by the rapid ongoing degradation of our ecosystem and the potential need for monitoring and localizing sources of greenhouse gas emissions. For example, the authors in [15] demonstrate the importance of finding methane leaks for holding oil and gas suppliers accountable and for identifying the causes of such leaks. Among other options, the authors suggest using aircraft for remote sensing. This could be accomplished by using drones or uncrewed air vehicles (UAVs). These UAVs would have to be equipped with adequate sensors, they would survey a given land area or volume of atmosphere, and wirelessly report their findings to an information fusion center.

We asked our students to set up a simulation framework using MATLAB and Simulink that would allow them to (a) control one or more drones and to let them autonomously cover a desired region, and (b), to simulate a network model for the communication between a drone and a ground station. Furthermore, they were asked to (c) provide results of their simulated communication performance with respect to the chosen flight pattern and communication technology.

Students reported their progress in weekly meetings with the project advisors. In addition, they presented their results in three milestone meetings to the students and advisors participating in Telecommunication Networks semester projects of the same semester.

A. Project Outputs

Based on the UAV Toolbox,¹ the students worked on a Simulink project for simulating a UAV. The UAV flies in an environment where CO₂ molecules are diffusing from a set location. A screenshot of this setup is shown in Fig. 2.

Their framework furthermore includes a selection of flight paths that can be configured for the drone. Fig. 3 shows a spiral pattern; other patterns are also supported, for example like covering a rectangular area by flying back and forth between two of its sides, optionally in multiple vertical layers.

Furthermore, the group provided the means to plot the concentration of CO₂ in the air as well as the distance to the emission source. One example of such a plot is shown in Fig. 4, which shows the number of CO₂ molecules measured in simulation out of a total of 200 released molecules in relation to both the simulation time and the distance to the source. It can be seen that the detected CO₂ concentration increases over time in the periods when the UAV is keeping a constant distance to the emission source, e.g., between 0–60 s. This can be explained by the effect of molecules diffusing away from the source. As expected, moving away from the source also leads to a lower concentration of detected molecules.

III. PROSPECTIVE APPLICATIONS IN THE K-12 LEVEL

The above simulator assembled by students provides a platform to design hands-on activities at the K-12 level. Here we illustrate one potential activity on localizing the source of CO₂ emissions in the air with drones. We design these activities for the grade levels in the range 9–12th. Using the simulator, we expect students to discover the coordinates of the source when measuring concentration levels with the flying drone (cf. Fig. 5).

To simplify the problem, we consider a scenario where the source is a single point. The source releases CO₂ molecules according to the Dirac distribution. We also assume those molecules diffuse freely into the environment, that is, there is no impact from wind or any other emission source. At an arbitrary distance from the source, the drone can measure the concentration level according to [17, Eq. (6)]:

$$c(\mathbf{p}_d, t) = \frac{N}{(4\pi Dt)^{\frac{3}{2}}} e^{-\frac{\|\mathbf{p}_d - \mathbf{p}_s\|^2}{4Dt}}, \quad (1)$$

where $\mathbf{p}_d = [x_d, y_d, z_d]$ is the position of the drone, $\mathbf{p}_s = [x_s, y_s, 0]$ is the unknown position of the source (placed on the ground to simplify the problem), D is the diffusion coefficient of CO₂ molecules, N is the total number of released molecules by the source, and t is time.

Using the relation in Eq. (1), the goal is to devise a method to compute the unknown location of the source as \mathbf{p}_s . This is achieved by evaluating this relation at two different locations of the drone, then solving for the two coordinates of the source as x_s, y_s . The simulator will provide the sequence of two values $c_1(\mathbf{p}_1, t_1)$, $c_2(\mathbf{p}_2, t_2)$ and the student should use available pre-defined functions to solve the system of equations.

¹<https://de.mathworks.com/solutions/robotics/uav.html>

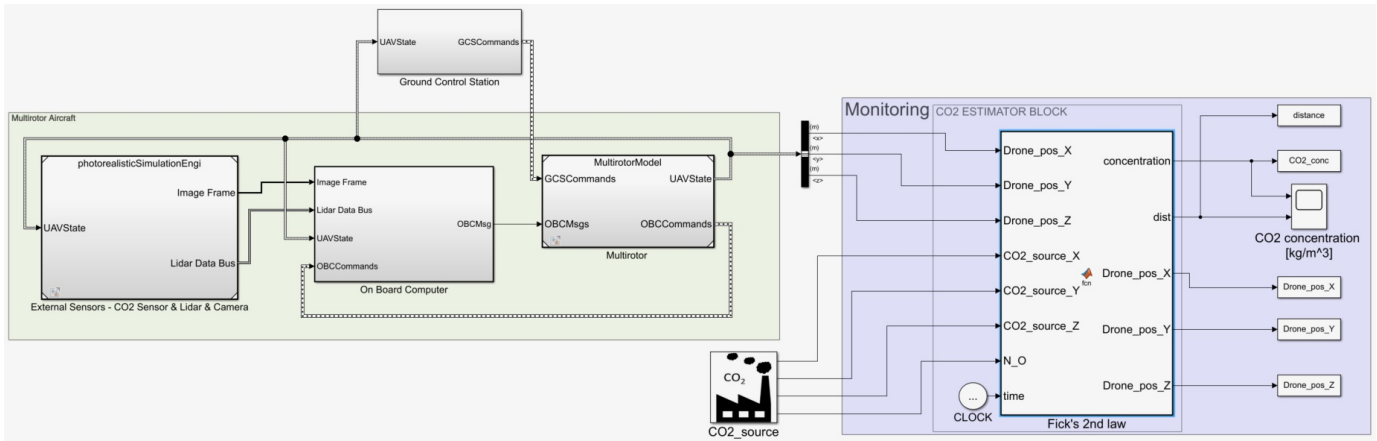


Fig. 2: Simulink design to control the drone path [16].

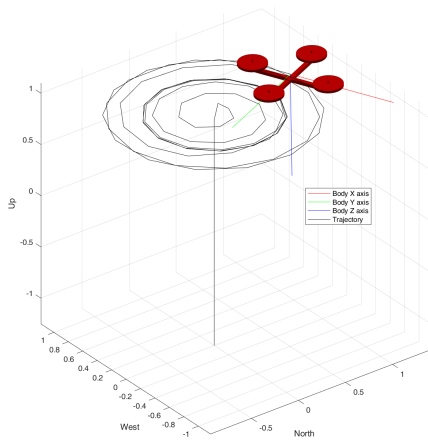


Fig. 3: Example of implemented drone trajectory.

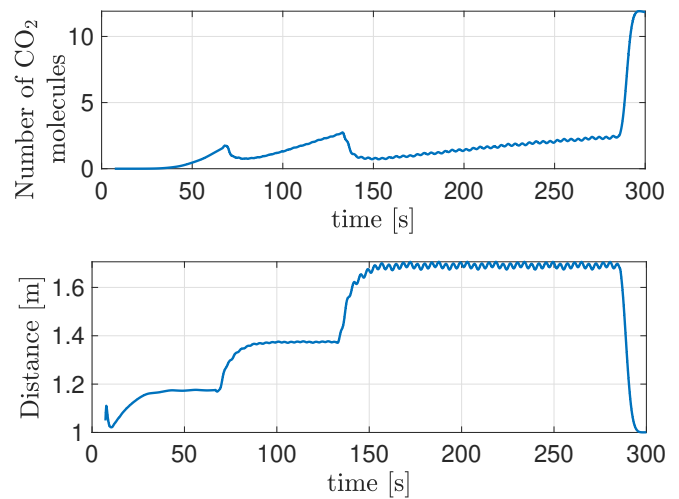


Fig. 4: Measured CO₂ total of molecules and distance to the emission source.

In the classroom, students may write a code following the steps in Fig. 6. Steps 1–2 are the initializing steps to set the drone path, the source and diffusion parameters, and the sampling time. Steps 3–6 are related to the solution of Eq. (1) for \mathbf{p}_s . We provide public access to the simulator platform and the code in [18]. The algorithm is specified in the file `stop_fcn.mlx` as located in the `work` directory.

When addressing this problem, instructors may introduce not only the fundamentals for Fick’s law and the algorithm to solve the problem, but also content related to climate change and the corresponding metrics related to CO₂ concentration levels. For instance, the total number of CO₂ molecules released per unit of time in factories, the meaning of the diffusion coefficient, and their impact on pollution. The instructor may also introduce the history around the discovery of Fick’s law to get Eq. (1). In the following subsections, we provide more insights into the instructor guidelines.

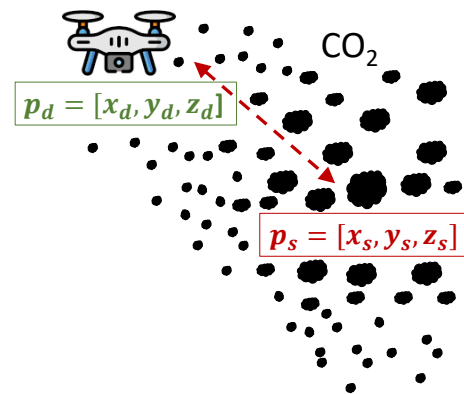


Fig. 5: Scenario for the illustrative example at the K-12 level.

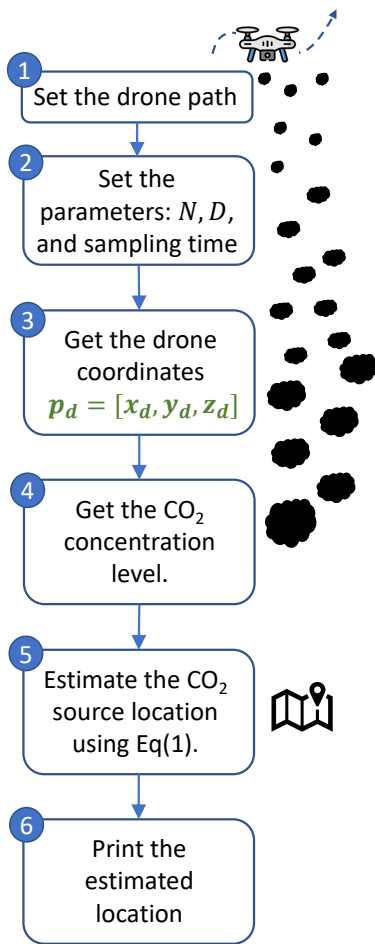


Fig. 6: Sequence of steps to estimate the source of emissions.

A. Lesson Plan

Using this platform, the instructor may conduct various on-site activities at the K-12 education level (we design these for students in the range 9–12th class). Here we provide some examples with three lessons, two hours each, as follows:

1) *Lesson 1 “CO₂ in the spot”*: As **learning objective**, the students must reach an overview of the impact of CO₂ emissions and how to assess it. The **teaching activity** related to this session is in a workshop format addressing the following topics (including references to online content)

- Chemistry of greenhouse gases such as CO₂, infrared absorption, the greenhouse effect, and diffusivity research: The instructor may introduce some basics on the chemical formulation of CO₂ molecules and discuss the absorption coefficient as a function of electromagnetic wavelength in the context of the greenhouse effect; notes on the fundamentals and the history of Fick’s second law are accessible in [19].
- Historical measurements of CO₂ levels in the atmosphere,² its impact in the atmosphere, and efforts conducted to

²e.g., <https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide>

measure it [14].

- Examples of CO₂ emission sources and their emission rate: Figures can be provided considering engines from vehicles, factories, and natural processes like volcano emissions.
- Climate-friendly technologies, challenges and their controversies: Examples can be illustrated with the initiatives to vacuum up CO₂ from the atmosphere in farms [20], or by seaweed cultivation in the ocean [21]. Artificial means as carbon removal factories are also part of the top-10 breakdown technologies [22], as well as drones reversing deforestation [23].
- Actions and demands of social movements: Various groups push for governmental policies to reduce CO₂ emissions; an example is the climate justice movement Fridays for Future [24].

The instructor may prepare the content to introduce these topics using online videos and slides using the links provided above. As **materials**, the instructor may need access to an internet-connected computer and a projector with audio speakers. Additionally, with some inexpensive sensor meters, students can conduct outreach activities when measuring the CO₂ concentration level in the surrounding environment.

2) *Lesson 2 “Flying the drone”*: As a **learning objective**, the students must understand the interactions between main components in the simulator that makes the drone fly. In this lesson, the **teaching activity** is to introduce the drone simulator in the Simulink environment and run the design with the variety of flight mission options for the drone. Using the project available in [18], students can get familiar with main components and their interfaces as (cf. Fig. 2)

- **Ground Control Station** block: This block comprises 7 missions for the drone to fly. It provides the command to the **Multicopter** block for the drone to fly. The missions are activated when un-commenting the block of interest and commenting-out the others. Missions are accessed navigating with double-click through the blocks **Ground Control Station** → **Get Flight Mission** → **noQGC**.
- **CO₂_source** block: This block provides the coordinates for the CO₂ source of emissions and the total of emitted molecules. This is assumed to be 200 according to measurements in industrial parks [25].
- **Monitoring** block: This block simulates the CO₂ sensor. It evaluates the Eq. (1) based on the drone position, the CO₂ source, and the simulation time.

The instructor must also explain how these blocks interact with each other through their interfaces. Using the graphical user interface, students can participate in this lesson without complete knowledge of MATLAB. In this way, the lesson will cover control structures as a CS concept. The student may provide a different path trajectory for the drone as a hands-on activity. Commenting and uncommenting blocks, students can specify the path coordinates with time in the block **Ground Control Station**. As **materials**, the lesson needs com-

puters with internet access (1–2 students per computer), and an Internet-connected computer and a projector.

3) *Lesson 3 “Discovering the CO₂ emission source”*: As a **learning objective**, the students will learn to program the estimation procedure for the CO₂ source location with text code in MATLAB. As **teaching activity**, the instructor will guide the students to insert code in the `stop_fcn.mlx` file. This is accessible in the work repository [18]. Students will follow the steps represented in Fig. 6. Steps 1–3 are already provided by the simulator, although the parameter N (total of emitted CO₂ molecules) can be adjusted depending on the target to locate (vehicle, factory, natural process). The student must program Step 5 using the MATLAB function `vpasolve` with the given drone coordinates. Using the solution provided in the repository, the instructor may implement the approach “use-create-modify” to teach some mathematics while coding [11]. Hiding some portions of the code, students can be asked to complete it. For instance, due to the need to evaluate two equations to solve for the source’s two coordinates, one equation can be given, and students can be asked to provide the second one. As **materials**, computers with internet access (1–2 students per computer), an Internet-connected computer, and a projector are required.

B. Remarks

This lesson plan can be further extended in case of having access to a drone connected to the computer to conduct other reach-out activities. For instance, Lesson 2 can be extended to another lesson when flying the drone with the predefined coordinates by students following the methodology. Similarly, Lesson 3 can be extended to another lesson to measure the concentration level of CO₂ in the atmosphere and follow the steps from Charles Lowe [14].

IV. CONCLUSION

This paper documented a synergistic approach to producing materials at universities that later support K-12 education. Usually, students conduct projects at universities providing technical platforms, which also become valuable tools for promoting STEM. We foresee this approach as one direction that naturally pursues the promotion of STEM topics at the K-12 level. In future work, we will conduct efforts to exclusively develop free and open-source tools that students can use at home on any computer. Such tools would remain free to use after leaving school.

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REFERENCES

- [1] “Statistics | Eurostat.” [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/sdg_04_20/default/table?lang=en
- [2] “TU Berlin Statistics.” [Online]. Available: <https://www.tu.berlin/en/about/profile/tu-berlin-statistics/>
- [3] “Gender Equality & Diversity.” [Online]. Available: <https://www.tu.berlin/en/working-at-tu-berlin/working-life/gender-equality-diversity/>
- [4] “Coding arkistot.” [Online]. Available: <https://tryengineering.org/tag/coding/>
- [5] “Fun, Free Minecraft Lesson Combines Coding with History,” Dec. 2021. [Online]. Available: <https://tryengineering.org/news/fun-free-minecraft-lesson-combines-coding-with-history/>
- [6] “Google’s Made with Code.” [Online]. Available: <https://tryengineering.org/student/googles-made-with-code/>
- [7] “Tinkercad.” [Online]. Available: <https://tryengineering.org/student/tinkercad/>
- [8] V. Garneli, M. N. Giannakos, and K. Chorianopoulos, “Computing education in K-12 schools: A review of the literature,” in *2015 IEEE Global Engineering Education Conference (EDUCON)*. Tallin, Estonia: IEEE, 3 2015.
- [9] P. Sengupta and A. V. Farris, “Learning kinematics in elementary grades using agent-based computational modeling,” in *11th International Conference on Interaction Design and Children (IDC ’12)*. Bremen, Germany: ACM Press, 6 2012.
- [10] W. W. Lau, G. Ngai, S. C. Chan, and J. C. Cheung, “Learning programming through fashion and design,” *ACM SIGCSE Bulletin*, vol. 41, no. 1, pp. 504–508, 3 2009.
- [11] G. Kacmarcik and S. G. Kacmarcik, “Introducing computer programming via gameboy advance homebrew,” in *40th ACM technical symposium on Computer science education (SIGCSE ’09)*. Chattanooga, TN: ACM Press, 3 2009.
- [12] O. Meerbaum-Salant, M. Armoni, and M. Ben-Ari, “Learning computer science concepts with scratch,” in *Sixth international workshop on Computing education research (ICER ’10)*, Lugano, Switzerland, 8 2010.
- [13] K. Qiu, L. Buechley, E. Baafi, and W. Dubow, “A curriculum for teaching computer science through computational textiles,” in *12th International Conference on Interaction Design and Children*. Albany, NY: ACM, 6 2013.
- [14] D. C. Lowe, *The Alarmist: Fifty Years Measuring Climate Change*. Victoria University of Wellington Press, 2021.
- [15] R. A. Alvarez, D. Zavala-Araiza, D. R. Lyon, D. T. Allen, Z. R. Barkley, A. R. Brandt, K. J. Davis, S. C. Herndon, D. J. Jacob, A. Karion, E. A. Kort, B. K. Lamb, T. Lauvaux, J. D. Maasakkers, A. J. Marchese, M. Omara, S. W. Pacala, J. Peischl, A. L. Robinson, P. B. Shepson, C. Sweeney, A. Townsend-Small, S. C. Wofsy, and S. P. Hamburg, “Assessment of methane emissions from the U.S. oil and gas supply chain,” *Science*, vol. 361, no. 6398, pp. 186–188, 6 2018.
- [16] “UAV Package Delivery - MATLAB & Simulink.” [Online]. Available: <https://www.mathworks.com/help/uav/ug/uav-package-delivery.html>
- [17] V. Jamali, A. Ahmadzadeh, W. Wicke, A. Noel, and R. Schober, “Channel Modeling for Diffusive Molecular Communication—A Tutorial Review,” *Proceedings of the IEEE*, vol. 107, no. 7, pp. 1256–1301, 7 2019.
- [18] J. Torres Gómez, L. Stratmann, D. Busse, I. Can, and O. Karaahmetoglu. (2022) CO2 emissions drone surveillance. [Online]. Available: <https://www.mathworks.com/matlabcentral/fileexchange/114035-co2-emissions-drone-surveillance>
- [19] J. Philibert, “One and a Half Century of Diffusion: Fick, Einstein, Before and Beyond,” *The Open-Access Journal for the Basic Principles of Diffusion Theory, Experiment and Application*, vol. 4, pp. 1–19, 2006.
- [20] C. Crownhart, “This CRISPR pioneer wants to capture more carbon with crops,” *MIT Technology Review*, Jun. 2022. [Online]. Available: <https://www.technologyreview.com/2022/06/14/1053843/carbon-capture-crispr-crops/>
- [21] J. Temple, “Running Tide is facing scientist departures and growing concerns over seaweed sinking for carbon removal,” *MIT Technology Review*, Jun. 2022.
- [22] J. Temple and C. Crownhart, “Carbon removal factory,” *MIT Technology Review*, Feb. 2022. [Online]. Available: <https://www.technologyreview.com/2022/02/23/1044972/carbon-removal-factory-climate-change/>
- [23] R. Chandler, “Can Seeds Planted by Drones Spawn New Forests?” *The New York Times*, Oct. 2021. [Online]. Available: <https://www.nytimes.com/2021/10/31/climate/deforestation-seeds-environment.html>
- [24] “Startseite | Fridays for Future.” [Online]. Available: <https://fridaysforfuture.de/>
- [25] K.-Y. Wang, J.-L. Wang, and W.-T. Liu, “Ambient carbon dioxide concentrations in industrial park areas: A monitoring and modeling study,” *Atmospheric Pollution Research*, vol. 5, no. 2, pp. 179–188, 4 2014.