Using field trips in engineering education to facilitate the understanding of energy systems and technologies: an overview

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Abstract

Can field trips provide a more efficient way of teaching energy systems and technologies at the university level? This paper provides an overview of how field trips could be used to teach students the fundamentals and complexities of energy systems and energy technologies. It contains an overview of learning objectives related to the UN Sustainable Development Goal 7 (clean and affordable energy) as well as teaching methods that could be used during a field trip programme. This paper uses the findings of five weeklong field trips for university students as a case study to shed light on the benefits of such an educational experience. These visits included visits to production sites, governmental and corporate stakeholders of the energy system in different regions in Germany. The paper then proposes a schedule for a multiple-day field trip and suggests a general programme in four categories (political institutions, production sites, civil society and research institutions) for a better understanding of energy systems and technologies.

Keywords: field trips, engineering education, energy systems, energy transitions, community-based learning

1 Introduction

Visits to industrial production sites and organisations have been part of the university-level engineering curriculum for decades. Field trips are a component of engineering education and provide an important extension to the engineering curriculum. They facilitate an understanding of how engineering challenges are addressed in practice and bring students in contact with technologies and current challenges in industry. Broman (1994) describes two major contributions of field trips: firstly, they create an interest in the subject itself and secondly, they provide "sufficient connection with the real world to facilitate students' use of their knowledge". Further examples include teaching plant and process safety to chemical engineers (Amaya-Gómez et al., 2019) as well as in the education for energy mangers (Ciriminna et al., 2016). These visits can also be used to show how sustainability principles can be incorporated and to stimulate discussions whether such approaches can be scaled up and scaled out (Fenner et al., 2014).

Major recent review papers of engineering for sustainable development and reviews of teaching methods for engineering refer to field trips as one option for extending lectures: for example, Nesbit et al. (2013) mention project-based learning and field trips as possible methods in their comparison of "Educational Principles for Engineering Education for Sustainable Development". Similarly, field trips are mentioned as a method to teach circular economy (CE) principles (Kirchherr and Piscicelli, 2019). Lozano et al. (2017) review pedagogical approaches in higher education and explain how they affect sustainability competences. They describe various teaching methods (case studies, inter-disciplinary team teaching, lecturing, project-based learning, community service learning, participatory action research among others). Overall, they describe several elements, but do not include the concept of field trips in their list of teaching methods.

Case studies of field trips, the learning outcomes, teaching methods and educational approaches have occasionally been presented at EESD conferences. Key features include a better understanding of manufacturing technologies and their implementation, direct contact with industrial companies, as well as discussions with stakeholders. However, descriptions and case studies of field trip-based learning experiences are rarely published in engineering education journals (but inform the writing process of them). The details of the planning of a field trip, the learning objectives and potential items of a programme of a multiple-day field trip are, however, not described further in these papers and the literature on multiple-day field trips is sparse in the published literature on engineering education. This might provide an opportunity for further work in this area. Further research could also include a more systematic review of literature on field work and site visits (including other disciplines such as geology).

The goal of this paper is to shed light on how these educational programmes could facilitate the understanding of the complexities associated with the Sustainable Development Goal (SDG) 7 "Clean and Affordable Energy for All". Based on a case study of five one-week field trips that were conducted in Germany, the paper will address the following two questions:

1. What are the factors to consider when designing a field-trip based learning experience related to energy and the energy transition?
2. How can the complexities of an energy system, including technologies, systems, stakeholders and transitions be taught to students during a field trip?

There are different options for including field trips into the engineering curriculum with a duration ranging from a couple of hours to multiple days. This case study describes options for including energy-themed site visits into a week-long field trip programme around issues of the energy transition in Germany. Five independent week-long field trips were conducted between 2016 and 2019 in different regions in Germany with groups of 20-25 students per trip from different disciplines. The field trips were funded by the Studienstiftung (a German educational foundation). The visited organisations which included governmental and non-governmental stakeholders, production sites, power plants, research institutions, and museums. An example schedule is provided in Table 4 in the Appendix.

The field trips were followed by discussions and reflections in the team of organisers which were used systematically to summarise and analyse lessons learned for organising field trips and designing the learning experience. Over the five field trips, the programme items and aspects of "good practice" were identified and continuously improved. The findings from the field trips organised were extended by a literature review on the published examples of field trips in engineering education. These were then summarised for this conference paper to highlight the potential contributions and learning outcomes of field trips.

In the next section, the potential contributions of field trips in engineering education and methods used during field trips will be summarised. Then, the energy field trip programme and some anecdotal evidence of findings that highlight the benefits of this teaching experience are presented.

2 Field trips for exploring aspects of the *Energy System Transition*

2.1 Potential contributions and learning outcomes of field trips

Field trips could help to systematically teach and analyse engineering challenges such as the transition towards renewable energy sources, and the stakeholders involved in addressing the challenges on a societal level. The learning outcomes can be divided into learning outcomes relevant for all engineering disciplines, and learning outcomes specific for a better understanding of SDG 7. Field trips can be used to expand the technical knowledge, the political and economic relevance of energy topics.

Technical dimension:

- teach students which processes are currently used in industry and facilitate an understanding of how the theoretical knowledge (e.g. combustion processes, heat transfer) is applied in technologies in practice,
- show and assess the difficulties of scaling up and out (e.g. renewable energy sources such as wind turbines or solar panels),
- highlight technological alternatives and their similarities and differences (e.g. different material demand and/or different efficiencies).

Economic dimension:

- show how engineering and technology are embedded in society and show the diversity of stakeholders in the energy system,
- bring students in contact with potential employers after graduation (e.g. small and large corporate, governmental, and research institutions),
- facilitate an understanding of the scale of production sites and the lock-in into current capital-intensive production equipment (e.g. power plants).

Socio-political dimension:

- facilitate a discussion about the challenges of long-term actions that require coordination between different stakeholders,
- help to understand the challenges of policy implementation (e.g. political processes and barriers) and help to inform better policy conclusions from research papers and reports.

The report on Education for SDGs by UNESCO (2017) provides an overview of the SDGs and the learning objectives in three categories: cognitive, socio-emotional and behavioural learning objectives. Table 1 provides an overview of the learning objectives related to SDG 7. The learning objectives from UNESCO (2017) were extended with further learning objectives and suggestions for programme items based on the findings during the field trips.

The table shows that most of the learning objectives can be covered during site visits or workshops as part of a field trip programme. In addition to the three main categories, further energy-related learning objectives were identified. These are the sociocultural, economical and historical embeddedness of stakeholders of the energy system. Furthermore, the institutional arrangements and relevant stakeholder companies, civil organisations as well as governmental institutions and their role in shaping energy systems can be taught through the site and organisation visits.

Table 1: Learning objectives related to SDG 7: clean and affordable energy as described in UNESCO (2017) with an example and the suggested duration if included in a field trip experience.

Learning Objective	Description from UNESCO (2017)	Examples	Suggested Duration
Cognitive learning objectives	1. The learner knows about different energy resources – renewable and non-renewable – and their respective advantages and disadvantages including environmental impacts, health issues, usage, safety and energy security, and their share in the energy mix at the local, national and global level.	Visits of coal mine, wind turbine, biogas plant, coal- or gas-fired power plant.	4-8h
	2. The learner knows what energy is primarily used for in different regions of the world.	Lecture or presentation, seminar with overview, introductory reading material.	1-3h
	3. The learner understands the concept of energy efficiency and sufficiency and knows socio-technical strategies and policies to achieve efficiency and sufficiency.	Discussions with stakeholders, site-visit and seminars.	2-4h
	4. The learner understands how policies can influence the development of energy production, supply, demand and usage.	Discussions with stakeholders, and visits of political organisations.	1-3h
	5. The learner knows about harmful impacts of unsustainable energy production, understands how renewable energy technologies can help to drive sustainable development and understands the need for new and innovative technologies and especially technology transfer in collaborations between countries.	Company visit, production sites, discussions during and after site visits.	1-3h
Socio-emotional learning objectives	1. The learner is able to communicate the need for energy efficiency and sufficiency.	Seminars with reflective elements and documentation of the field trip.	1-6h
	2. The learner is able to assess and understand the need for affordable, reliable, sustainable and clean energy of other people/other countries or regions.	Seminars and workshops with interactive discussions.	1-4h
	3. The learner is able to cooperate and collaborate with others to transfer and adapt energy technologies to different contexts and to share energy best practices of their communities.	Seminars and workshops with interactive discussions.	1-4h
	4. The learner is able to clarify personal norms and values related to energy production and usage as well as to reflect and evaluate their own energy usage in terms of efficiency and sufficiency.	Site visit with follow-up discussions, and workshops.	2-8h
	5. The learner is able to develop a vision of a reliable, sustainable energy production, supply and usage in their country.	Seminars and workshops with interactive discussions.	2-4h
Behavioural learning objectives	1. The learner is able to apply and evaluate measures in order to increase energy efficiency and sufficiency in their personal sphere and to increase the share of renewable energy in their local energy mix.	Seminars and workshops with interactive discussions.	2-4h
	2. The learner is able to apply basic principles to determine the most appropriate renewable energy strategy in a given situation.	Seminars and workshops with interactive discussions.	2-4h
	3. The learner is able to analyse the impact and long-term effects of big energy projects (e.g. constructing an off-shore wind park) and energy related policies on different stakeholder groups (including nature).	Coal mine or production site visit and discussions with stakeholders.	2-8h
	4. The learner is able to influence public policies related to energy production, supply and usage.	Workshop and interactive discussions with political stakeholders.	2-4h
	5. The learner is able to compare and assess different business models and their suitability for different energy solutions and to influence energy suppliers to produce safe, reliable and sustainable energy.	Site visits with interactive discussions, seminars and workshops .	2-8h
Additional contextual learning objectives	1. The learner understands the historical context of the local energy system.	Museum visits and discussions with stakeholders.	1-3h
	2. The learner understands the limitations and potentials for scale-up and scale-out.	Seminars and workshops with interactive discussions.	1-3h
	3. The learner knows the political and institutional arrangements in a local context.	Visit of governmental institution, discussion with political stakeholders.	1-4h
	4. The learner understands the use of energy in industrial production processes and manufacturing and potential improvements with regard to material and energy efficiency.	Production site and company visits, documentation of site visits and short technical analysis (e.g. energy and material balance).	2-8h
	5. The learner understands the local importance of companies and production sites as employers and tax-payers – and potential constraints for an energy system transition.	Production site and company visits.	2-8h

2.2 Teaching methods

Various teaching methods can be used during engineering field trips. These include methods commonly used in engineering education, field trip specific methods and other methods for documenting and reflecting on the learning experience. The teaching methods range from visits to production sites to semi-structured interviews and typical teaching formats of the university curriculum (including presentations, seminars, and workshops). Table 2 summarises a selection of these teaching methods, a brief description, the contribution to the learning outcomes as well as an example and estimate of the time for execution and preparation.

Table 2: Overview of teaching methods that can be used in multiple-day field trips

	Teaching Method	Description	Contribution to the Learning Objectives	Example in Field Trip	Time of Method	Time for Preparation
During site visit	Production site visit	Group visits to production sites with production processes or engineering equipment.These could include power plants, manufacturing companies or bulk material production process.	Understanding of the production process, historical developments, current processes and limitations to changing them. Understanding the application of engineering knowledge in practice.	Guided tour through a coal-fired power plant or steel production site.	2-8h	1-4h
	Research institution visit	Group visits to a large research institution or research unit of a company. The focus could be on the understanding of current and published research (presentations) or the tools methods for doing research in this area (laboratory visit, software demonstration), and discussing current activities.	Overview of current research topics, methods and questions.	Major research center (e.g. Fraunhofer) or university department.	2-8h	1-4h
	(Audio-) Guided tour in cultural institution	(Audio-)Guided tour in a cultural organisation or place. This includes museums, exhibitions as well as other significant places (e.g. former mines).	Overview of energy systems over time, historical relevance of production sites and technologies; cultural aspects of energy technologies.	Local museum or exhibition on energy-related topics (science and technology museum, history of the region).	1-4h	1-2h
	Semi-structured interview	Semi-structured interview with a stakeholder. The prepared questions provide a general frame and set the stage. The spontaneous questions of students to clarify points and allow an interactive discussion.	Understanding complexities and diversity of stakeholders involved in energy systems, political processes and organisations.	Interview with a representative of a political institution; current or former member of a parliament.	1-4h	1-6h
Directly before or after the visit	Presentation and discussion	The presentation could be on research topics and projects, practitioners' insights or a general overview of a topic. The presentation is similar to a lecture, but could provide further insights if given by a local stakeholder. The presentation should be limited to 45min in order to allow for sufficient time for questions and discussions.	Overview of a topic and insights into practical challenges and how to address them.	Presentations by engineers working in project management, civil servants, journalist, or researchers.	1-4h	1h
	Movie	A movie screening (with a movie related to energy) could help to provide some time to relax and a passive acquisition of contextual knowledge. Movies, especially documentaries, could provide additional perspectives and could be used as a reference point in discussions with stakeholders.	Visual overview and information on topics that can not be covered in site visit or common presentation.	Movie on biofuel production and its effects on agriculture.	1-2h	–
	Seminar	A seminar can be included in the programme to prepare a site visit, to reflect on the visit and to discuss open questions.	Process understanding, room for asking questions and identifying further research questions or information needs.	Seminar preparing and reflecting on site visit.	1-2h	1-6h
	Workshop	An interactive workshop can be used for group exercises, role play and simulation games.	Problem-based learning; interactive discussion of possible improvements in a production site to increase energy efficiency or sustainability.	Workshop on "Tragedy of the Commons".	1-8h	1-20h
Before or after the field trip	Travel and discussions	Travel with different means of transport (walking, cycling, train, bus) to go to the next station in the programme (e.g. production site or research institutions) and to facilitate conversations among participants.	Required for getting to programme items. Different means of transport can be used for reaching the destination.	1.5 hour-long journey to a remote production site.	1-2h	–
	Reading material	Material could be provided before and during the field trip. These could include journal articles, newspaper and magazine articles. Additionally, technical reports and governmental reports could provide an overview and show students examples of grey literature on energy.	Better understanding of the visited stakeholders, understanding of literature and sources of information; relevant information sources out of the "academic" literature.	Technical or research reports on programme items or energy-related topics, governmental regulation.	1-15h	1-2h
	Meeting before the field trip or follow-up meeting	The trip could be extended by a pre-meeting or a post-meeting. The meeting can take place physically or as a virtual meeting. This can be used for preparing the field trip, facilitating exchange among participants, discussing site visits and implementing ideas that resulted from the field trip.	Team-building before the trip and to bring all participants on a similar level of knowledge.	Physical preparation meeting before the field trip or phone conference.	1-8h	1-20h
	Documentation and reflective exercises	The participants can be encouraged to take notes of one programme item and to document the visit. The notes can then be summarised, extended and compiled into a report for all participants.	Mandatory reflection and encouraging note-taking during the site visits and discussions.	Summary of site visit, collection of questions and answers.	1-20h	1h

Further methods that could be included in a multiple day field trip are case study field work, learning-by-discovery and project-based learning (Ciobanescu and Ertekin, 2018). Seifan et al. (2019) propose the inclusion of *virtual* field trips (with virtual reality glasses) to prepare for a *real* field trip. Recent developments resulting from the lockdowns during the Covid pandemic have led to several innovations and opportunities for virtual site visits. These could be explored in further research.

3 Programme items and lessons from the field trips

A field trip on energy topics could cover many different programme items. This section summarises four main categories of stakeholders and three examples of learning outcomes that illustrate the complexities and how a field trip can be used to facilitate a better understanding of them.

The stations and stakeholders that can be included in a field trip programme very much depend on the local context, the time and resources available. The stakeholder institutions, which were visited during the previously conducted field trips, can be divided into four broad categories: (1) political institutions, (2) companies and production sites, (3) civil society and NPOs as well as (4) research institutions and other public institutions. There are, however, more stakeholders in the energy system which could be identified in a more detailed systems analysis, e.g. as described in Meadows and Wright (2009).

Table 3 provides an overview of stakeholders and production sites that could be visited to gain a more holistic understanding of the energy system.

Table 3: Overview of stakeholders in the energy system and potential programme items of an energy-themed field trip in Germany

Political Institutions	Production Sites and Company Visits	Civil Society and Non-Profit Organisations (NPOs)	Research Institutions and Other Public Institutions
Government (local, national, international)	Production and manufacturing companies	Environmental NGOs/NPOs	Universities and technical colleges, other educational institutions
Politicians	Power plants	Other local civil society actors	Research institutions (Fraunhofer, Max-Planck, Helmholtz, Leibniz
Public agencies (e.g. Environmental Agency)	Engineering offices, transport planning company	Grass-root initiatives	Research unit or laboratory in company
Administration	Other (financial institution, start-ups)	Citizens	Museums

The field trips all included at least one stakeholder from each group to provide a broad overview of the technological, economical and sociocultural aspects of energy systems. These different stakeholders are summarised in Table 3. Between the production site and stakeholder visits, there was time for seminars to prepare for the visits and to reflect on the visits in discussions. These discussions led to helpful insights into the non-technical aspects of energy system transitions.

Three examples from the visited stations illustrate the non-technical aspects; the context, the complexities and the diversity of stakeholders involved in decision-making:

1. **The embeddedness of a power plant in its environment.** A visit to a power-plant shed light on the technologies and fuels used for generating electricity and heat. These products are used by *companies* and *households* nearby. To build and operate a power-plant, permissions from a *local*

governmental authority are required and the power-plant needs to meet the emissions requirements set by *national and international governmental institution*s. The power plant operator provides work for *employees* and pays *taxes* that finance local governmental spending.

2. **Local initiatives that can be scaled up.** A local municipality government (e.g. Stuttgart) developed an energy efficiency programme to reduce the energy demand throughout the governmental offices in a city, e.g. by demand reduction, buildings refurbishments and LED lighting. The programme followed national targets set by the parliament, but was implemented by the local administration. Due to its success, its best practice was shared and "scaled-out" to municipalities and cities of a similar size and with similar challenges. At the same time, the state-level government developed ambitious plans for GHG emissions reductions, which were later implemented into federal level legislation.
3. **The complexity of coordinating stakeholders involved in industrial waste heat utilisation.** Large industrial production processes often produce heat that is not used within the process, but could be used for district heating. In the city of Hamburg, a copper producer had waste heat that could be used for district heating, but there were budgetary constraints and legal challenges to the utilisation. In order to overcome the non-technical challenges of using the heat (e.g. planning and building the infrastructure, financing the project and ensuring district heat demand), the company had to coordinate the actions with local stakeholders. The company then cooperated with the local energy utility company, a governmental bank, and the local government to successfully implement the project.

These examples highlight major non-technical aspects of engineering solutions and how they are driven and shaped by political and corporate stakeholders. They could to some extent be taught in lectures and workshops, but site-visits with interactive discussions with the stakeholders might facilitate a better and more time-efficient understanding of the complexities.

4 Conclusions

This paper provided an overview of factors to consider when designing a multiple-day field trip for engineering students and contains a proposal of learning objectives, teaching methods and programme items. Field trips can provide additional benefits (compared to traditional university teaching methods) in three broad areas: firstly, they help to identify and illustrate non-technical aspects of energy systems. Secondly, they help to understand the complexities in energy systems, the diversity of stakeholders involved and the time lag of implementing new technologies. Thirdly, they provide visual insights and (anecdotal) evidence of the "real world challenges" in companies, research and governmental organisations. By acquiring the knowledge about the challenges and barriers, students might develop better engineering solutions to address and solve them.

Learning objectives, teaching methods and potential programme items for an energy-themed field trip were suggested based on the experience of organising energy-themed field trips in Germany. The stakeholders of energy systems that could be visited during a field trip can be divided into four categories: political institutions, production sites, civil society and research institutions. It is suggested that a field trip should contain one programme item from each of the categories to ensure a broad learning experience and to facilitate a better understanding of the challenges of the transition towards sustainable energy systems.

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Further material that might be useful for implementing a field trip at university-level can be provided by the author on request.

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6 Appendix

Appendix A

Table 4: Example schedule of a field trip on energy systems, technologies and transitions

<table>
<tr><th>Time</th><th>Day 1 (Sunday)</th><th>Day 2</th><th>Day 3</th><th>Day 4</th><th>Day 5</th><th>Day 6</th><th>Day 7 (Saturday)</th></tr>
<tr><td>07:00</td><td rowspan="8">Arrival</td><td>Breakfast</td><td>Breakfast</td><td>Breakfast</td><td>Breakfast</td><td>Breakfast</td><td>Breakfast</td></tr>
<tr><td>08:00</td><td>Travel Time</td><td rowspan="2">Travel Time</td><td>Travel Time</td><td>Travel Time</td><td rowspan="2">Travel Time</td><td>Breakfast</td></tr>
<tr><td>09:00</td><td rowspan="3">**Power Plant Visit (A)**</td><td rowspan="5">**Production Site Visit or Company Visit (A)**</td><td rowspan="7">**Production Site Visit or Company Visit (B)**</td><td rowspan="3">**Seminar / Workshop**</td></tr>
<tr><td>10:00</td><td rowspan="2">**Museum Visit**</td><td rowspan="3">**Discussion with Governmental Stakeholders**</td></tr>
<tr><td>11:00</td></tr>
<tr><td>12:00</td><td>Lunch</td><td rowspan="2">Lunch (with Lunchbox)</td><td>Lunch</td></tr>
<tr><td>13:00</td><td rowspan="4">**Power Plant Visit (B) or Company Visit**</td><td>Lunch</td><td rowspan="9">Departure</td></tr>
<tr><td>14:00</td><td rowspan="3">**Visit of a Research Institution**</td><td>Lunch (with Lunchbox)</td><td rowspan="2">Travel Time</td></tr>
<tr><td>15:00</td><td>**Warm-Up**</td><td rowspan="2">Free Afternoon</td></tr>
<tr><td>16:00</td><td rowspan="2">**Seminar**</td><td>Travel Time</td><td rowspan="3">**Seminar**</td></tr>
<tr><td>17:00</td><td>Travel Time</td><td rowspan="2">Travel Time</td><td>Dinner</td><td rowspan="2">Dinner</td></tr>
<tr><td>18:00</td><td>Dinner</td><td>Dinner</td><td rowspan="3">**Presentation / Movie**</td></tr>
<tr><td>19:00</td><td rowspan="2">**Presentation**</td><td rowspan="2">**Presentation / Seminar**</td><td>Dinner</td><td rowspan="2">**Seminar / Workshop**</td><td rowspan="3">Dinner and Evening Programme</td></tr>
<tr><td>20:00</td><td>**Student Presentations**</td></tr>
<tr><td>21:00</td><td>Open Exchange</td><td>Open Exchange</td><td>Open Exchange</td><td>Open Exchange</td><td>Open Exchange</td></tr>
<tr><td>Overnight</td><td>Accommodation</td><td>Accommodation</td><td>Accommodation</td><td>Accommodation</td><td>Accommodation</td><td>Accommodation</td><td></td></tr>
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