



Energy Transition and the Future of Energy Research, Innovation and Education: An Action Agenda for European Universities

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Preface

Energy is an exciting challenge for universities today because of the need for multi-disciplinary collaboration in research and innovation and for new approaches to help professionals entering the energy sector acquire skills and knowledge. Achieving a low carbon economy involves tackling uncertainty and ambiguity about future energy supply, the energy mix, energy use and efficiency and working out how to address behavioural change and adaptation.

Marie Skłodowska Curie, once remarked that: “Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less.” Her observation is particularly pertinent now in the 21st century, when the “grand societal challenges” of energy transition and climate change seem formidable.

To meet these challenges, we need young people with bright ideas to break away from conventional thinking and establish new expertise. Science will continue to develop technological breakthroughs that advance the transition to renewable energy and universities can provide the right environment for nurturing and bringing such expertise to fruition. One of the big energy transition challenges is social, requiring us to overcome political, economic, behavioural, cultural and territorial barriers. Social sciences and humanities

are therefore as important as engineering and natural sciences, contributing theoretical and conceptual frameworks, methodologies and approaches to address the energy transition.

This *Action Agenda* was designed as part of the *UNI-SET Project* and has mobilised and drawn upon the skills of hundreds of academic experts at universities across Europe, to highlight best practices and propose new research and education actions to achieve the energy transition. Successful take-up of this Agenda will require complete engagement and commitment from all energy stakeholders: universities themselves, regional, national and European governmental bodies, industry partners (of all sizes), social organisations and citizens.

We encourage open debate and feedback on the merits and any shortcomings of this document, and keenly hope to move the agenda forward at European level.

Professor Rolf Tarrach
EUA President



6th UNI-SET Energy Clustering Event

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Executive Summary

One of the greatest challenges of the 21st century lies in the sustainable generation and use of energy. Providing a reliable supply of clean, affordable energy for all raises complex and significant technical, social, political, economic, legal and ethical issues that must all be addressed, often in combination, to ensure sustainable growth and development. Universities have a critical role to play as key energy stakeholders. After all, universities build capacity through the development of new knowledge, new understanding and new insights, and can therefore provide effective solutions to complex problems. They also enable a regular supply of highly educated, skilled people who develop and implement solutions to energy and other social challenges.

Universities are uniquely positioned to make a significant contribution because they can combine expertise from different research and education disciplines and consequently provide a non-biased environment for exploring and developing new ideas. New cross-disciplinary approaches will be required, so that different energy technologies, systems, economies and markets, new regulatory frameworks, consumer behaviour insights, and other social and cultural aspects are all combined to holistically solve the existing challenges.

This document aims to support the plans and ambitions of universities across Europe, to strengthen existing capacities by providing guidance that will allow them to take new initiatives and develop interdisciplinary cooperations to promote the innovative research and education required to overcome the energy challenge.

In order to achieve a cross/inter-disciplinary approach, this Action Agenda articulates a new vision for education, continued professional development and research in energy, which is currently focused on adapting university master's and doctoral programmes. The other driver for creating new energy employee profiles is obviously employers themselves. A detailed employer survey was conducted and fed into profile proposals such as: Energy System Scientists, Energy Economists, Energy Policy Makers, all of whom will contribute to developing a sustainable energy supply.

A set of key guiding principles is set out to help universities successfully adopt this Action Agenda. They propose the changes needed in university organisation and management and highlight the need to develop cooperations with other energy stakeholders, i.e.: industry, European, national and regional government, non-governmental organisations, citizens' groups and opinion-leaders in the media and politics. However, none of this will be possible without commitment from university leaders and a change of university culture to allow more student-led ideas and innovative initiatives, new models of learning, including the greater inclusion of digital technologies, a life-long commitment to the continued development of new energy-related professional skills by employers and employees and, last but not least, improved communication and sharing of resources and expertise, resulting in less duplication of work, creating more time to focus on developing new cooperations and the necessary interdisciplinary research and teaching skills.

To achieve this cross/inter-disciplinary approach, master's and PhD programmes will need to focus on the global energy challenges set

out in the SET Plan and Energy Union. This can be achieved by making master's programmes more challenge-based, shifting away from single focus topics. UNI-SET found that employers particularly value master's programmes that feature problem or challenge-based learning, particularly when the content addresses real issues in a company's economic and/or business environment, and also programmes that include social/human contexts such as ethics and user interactions.

PhD programmes are distinct from other academic programmes as they involve original research in a specific area to generate new knowledge and insights. They consequently tend to be narrow and focussed. However, doctoral programmes in the field of energy should equip successful students with an additional, broader understanding of how their research can be applied, as this is highly beneficial for careers at universities, in the energy industry and related business and public bodies, including regulatory agencies, NGOs, etc.

The proposed framework covers 24 broad topics for master's programmes in the energy field and analyses their content and value across several vertical axes, addressing requirements for background knowledge and understanding, design and implementation and employment skills potential. It covers 4 different aspects and implications: technical, economic, social and political. A further 3 energy areas are covered in more depth, exploring practical programme design for: Energy Efficiency, Smart Grids and Energy Systems, and Renewables Integration.

A holistic energy system approach and its necessary interdisciplinary elements will only evolve if existing boundaries are overcome. The framework and examples put forward are designed to indicate how this can be achieved, while further debate and exchange will evolve as universities move into the interdisciplinary area.

To help move this Action Agenda forward, it is important to create opportunities to establish a European university energy network to further refine and implement the agenda through discussions, sharing good practice and case studies. Universities are strongly encouraged to maintain regular contact with the UNI-SET project and to share their approaches and successes. University management and other related, supporting structures are also encouraged to engage and provide the right environment for proposals to prosper and to ensure a brighter future.

(This Action Agenda for European universities in tackling the energy transition arises from the European University Association's (EUA) involvement in the European Commission's SET-Plan policy process through its participation in the European Energy Research Alliance (EERA), and in particular via the creation of a European Platform of Universities in Energy Research and Education (EPUE). It also comes from EUA's experience in conducting a European Commission Coordination Action, in partnership with the European Institute of Technology (EIT), InnoEnergy Knowledge Innovation Community, entitled "Universities in the SET-Plan (UNI-SET)", which mobilised university research and education capacities from 2014 to 2017. The Action Agenda promotes innovative research and education activities of established universities in the energy field and seeks to support the plans and ambitions of many universities across Europe to strengthen their existing capacities, to start new initiatives and to develop interdisciplinary collaborations).

1. Introduction

This Action Agenda has arisen from the work of the UNI-SET project and its development of a Roadmap for European Universities in Energy.

The Agenda responds to a “bottom-up” demand for a European action-orientated approach from the many university energy education leaders and research experts engaged in the project who are committed to the energy transition and who seek to integrate this goal fully within their education and research programmes. As the work of the UNI-SET project progressed through capacity mapping and topic-focussed clustering events, as well as providing input to the European Commission SET-Plan key actions, the Steering Committee recognised that an overview was emerging that could be highly-effective in the implementation of the Roadmap.

This document, therefore, puts forth current thinking developed under the UNI-SET project in terms of best practice and innovation for the delivery of energy-related programmes across all disciplines in Europe. It also provides a new approach and framework for structuring new energy-related programmes. It goes beyond the formal contractual “deliverables” of the UNI-SET project and is presented as a “pathfinder” for universities, offering a subset of thematic areas for action while highlighting the multi- and cross-disciplinary nature of the energy challenge. One of the key aims is to define an approach that helps universities address the energy challenge by improving education in general.

The document primarily addresses universities that are responsible for developing, establishing, managing, operating, and delivering energy-related education and training programmes at the master’s and doctoral level. However, it can be used by all parties interested

in energy education, including those with political and policy perspectives. There is a clear need for greater interaction between universities and other energy stakeholders including European and national policy makers, industry and citizens at large in order to overcome some of the challenges. These new collaborations should span existing disciplinary boundaries, cross national borders and allow practices to be shared by developed and developing nations.

We are grateful to the many people who volunteered in creating this Action Agenda. The Acknowledgements and Appendix F section contain a list of all contributors.

Those who took the demanding role of lead author and editor of sections in the report deserve special mention: Torbjørn Digernes, (Norwegian University of Science and Technology, Trondheim, Norway), Chair of the UNI-SET Steering Committee and the EUA European Platform of Universities in Energy Research and Education (EPUE), for his leading and inspirational role throughout the process. Giovanni Vincenzo Fracastoro (Politecnico di Torino, Italy) and Michael Narodoslawsky (Graz University of Technology, Austria) for the section on energy efficiency. Wim Melis (University of Greenwich, United Kingdom) and Mihaela Albu (Politehnica University of Bucharest, Romania) for the section on energy systems. Johan Driesen (Katholieke Universiteit Leuven, Belgium, and EIT InnoEnergy) and Douglas Halliday (University of Durham, United Kingdom) for the section on renewables. Douglas Halliday and Wim Melis together with John Smith (Senior Adviser to EUA) for Chapter 2 and overview of the final text. Finally, and not least, Lidia Borrell-Damian (Director for Research and Innovation, EUA) and the UNI-SET project team for keeping the initiative on schedule.

2. Future Challenges and Opportunities in Energy Research, Innovation and Education

2.1. State-of-the-Art and Current Trends

Energy – A Global Challenge

One of the greatest challenges for 21st century society is the sustainable, low-carbon use of energy. Providing a reliable supply of clean, affordable energy for all raises complex and significant technical, social, political, economic, ethical and research integrity issues that must be addressed to ensure continued, sustainable growth and development. All contemporary societies rely heavily on energy. Economic growth is closely related to the reliability of energy infrastructure. Considering the environmental impact of the current energy mix, more sustainable methods of energy conversion and use are essential for the planet. This is acknowledged in three of the United Nations Sustainable Development Goals: *Affordable and clean energy*, *Sustainable cities and communities* and *Climate action*. It is therefore no surprise that this enormous challenge is being tackled by many including: industry, universities, politicians, NGOs and lobby groups.

Universities – Key Energy Stakeholders

Universities have a critical role to play in meeting these challenges and are key energy stakeholders. Universities build capacity through the development of new knowledge, new understanding and new insights, thereby providing effective solutions to complex problems. They also enable a regular supply of highly educated and skilled people who develop and implement energy and climate solutions. European universities are a very diverse cohort, reflecting a range of cultures, values and energy needs. As individual as some of these challenges may be, cooperation is a key element of our vibrant university culture and this strength will help make a significant contribution to developing effective solutions to the energy challenge. The UNI-SET project has already mapped out the wide-ranging, innovative energy-related education, training and research activity happening across Europe³. However, further cooperation between universities, industry and other key social players is essential to addressing complex energy challenges. In this context, the critical role that universities play may need greater recognition and promotion.

Universities are part of a constantly changing, fast-paced environment that requires flexible methods and a shift from delivering core knowledge to include greater emphasis on skills. This requires the inclusion of research approaches in all taught programmes. With the growing availability of technology-enhanced learning, there is a clear role for the delivery of knowledge allowing for flexible study and providing an efficient and stimulating learning experience for many. The growth in online education and training resources - available and being developed in the field of energy at many universities - will therefore play an increasingly important role in training future engineers, technical experts, policy makers, social leaders, economists and other key professions. The availability of new compact learning and training modules and online resources will

also be important for lifelong learning and continuing professional development, ensuring that knowledge and workforce expertise is informed by state-of-the-art thinking at European universities.

Universities unite expertise from different research and education disciplines and provide a unique environment for exploring and developing new ideas. They are therefore ideally placed to enable the development of robust and effective solutions to the energy challenge. However, the energy challenge requires new cross-disciplinary approaches to integrate different energy technologies, systems, economies and markets, and importantly, to embrace new regulatory frameworks and understand consumer behaviour in a social and cultural context (more information about the SHAPE Energy project and energy-related keywords in an interdisciplinary perspective in Appendix C). The demands of the transition to low-carbon energy and the increasing technical, financial and political complexities of our evolving energy systems require more emphasis on developing inter-disciplinary knowledge and skills. This is nicely reflected in the definition of an Energy Professional, proposed here as someone with “the set of knowledge, skills and attitudes required to provide the required quantity and quality of energy to every end-user at the lowest price, based on the consumption of minimal raw materials with minimum environmental impact, using a rational lifecycle covering all phases from production to end-use.” This definition also indicates that the need for cross/multi-disciplinary study is only a starting point that will need to evolve to a truly interdisciplinary education, in which subjects are analysed, synthesised and harmonised into a coordinated and coherent whole. These aims are obviously long term, so the *Roadmap for European Universities in Energy*⁴ establishes a range of actions universities can take to help them move forward using this Action Agenda.

The approach set out here is the result of significant discussion and consultation between European university energy experts over the past three years. As this report was mainly driven by the UNI-SET Steering Committee, Science, Technology, Engineering, and Mathematics (STEM) professionals had a large influence on it, and they acknowledge that social science and economic aspects should be discussed in more detail and invite anyone working in these fields to contact them and contribute to future versions. This cross/multi-inter-disciplinary element will only evolve if boundaries are overcome, which is what this group aims to achieve and help others achieve.

The SET-Plan

In a drive to overcome dependence on imported energy, the European Union has become a world leader in developing renewable and low-carbon approaches. This is reflected in the European Strategic Energy Technology Plan (SET Plan)⁵ - the key technology-pillar of the European Union's energy and climate policy that aims to accelerate the development and deployment of low-carbon technologies. The SET Plan seeks to implement new technologies and reduce costs by coordinating national research efforts and financing specific, key projects. It focuses on the implementation of close-to-market technologies to support the short-to-medium term objectives of the Energy Union and 2030 Energy Strategy. However, more will be needed to achieve the long-term objective of a low-carbon or carbon-neutral society that limits the rise in global temperatures to +2 °C by 2050.

New and improved technologies will be needed, which will help to open global markets and opportunities for cooperations beyond the EU, sharing some of the lessons learned across the globe. These technologies will need to be combined with knowledge and understanding of the human actions required to achieve carbon neutrality. Tackling the role of consumers and citizens will be key to understanding the social acceptability of technologies and how they are adopted daily, as well as how their costs and benefits help us to reach a low carbon society. As the SET-Plan focuses on technology to deploy technical solutions, these solutions will be best developed with contributions from universities that build on the approach advocated here.

In advancing innovations in energy technology, the SET-Plan has recognised that one of the key elements for successful implementation at European level is the availability and mobilisation of appropriately skilled human resources. This is described in more detail in the *SET Plan Roadmap on Education and Training*⁶. The Action Agenda seeks to achieve the significant technical ambitions articulated in the SET Plan, capitalising on the expertise, resources and capacity building offered by all European universities. UNI-SET has already provided expert input to many SET-PLAN policy papers⁷ (for a full list of experts, see Appendix G).

Employer Profiles

Students and researchers that graduate with these new profiles will include: Energy System Scientists/Engineers, Energy Economists and Energy Policy Makers. They will all contribute to developing solutions to the energy challenge. To gain a better understanding of the needs for these new profiles, the UNI-SET project interviewed a variety of energy-related companies and used this information to develop a range of profiles⁸. The data used to draft this document can be combined with recent university decisions adopting new and innovative approaches to successfully educate and train individuals capable of building bridges to get all these different groups working together to solve energy challenges. This holistic perspective of the energy system builds on and operates between established disciplinary specialisations including: Mechanical Engineers, Electrical Engineers, ITC Specialists, Management Sciences, Social Sciences, Economics, Policy Makers, and Experts in Inter-disciplinary Dialogue. While the groundwork has been done in many cases, there is still a significant amount of work pending.

The Action Agenda Vision

This Action Agenda is designed to articulate a new paradigm for energy education, training and research, to create and adapt university master's and doctoral programmes and life-long learning programmes for employees, using new knowledge generated by research. Based on this foundation, future work can also address the renewal of bachelor's degree programmes, as these feed into post-graduate programmes and will need to change accordingly. The latter changes will start with a recommendation of which programmes feed into which post-graduate programmes, to produce a gradual adjustment making these bachelor's programmes more cross/multi and finally inter-disciplinary. In order to achieve the SET Plan ambitions, the key objective is to develop new scientific and technical expertise and skills in the sciences, anthropology, sociology, psychology, economy, and law and regulations. Considering that very

few individuals currently have such a varied background, there will be a transition period during which educators will need to work together to bring disciplines within reach and teach students towards this direction.

The integration of a broad range of social perspectives and technology challenges into university energy education and research programmes is therefore key. Such interdisciplinary work across engineering, social sciences, sciences and the humanities must be firmly embedded in university energy programmes. It must also be more than an add-on. It requires all academic disciplines to recognise that energy-related perspectives backed by knowledge from all disciplines bring value to energy solution development, and help achieve real progress and change. This inter-disciplinary approach must also span a range of technical areas. After all, a holistic approach needs to address all components of the future smart system with an understanding of the social and human interactions at play.

The UNI-SET project has identified a number of examples of innovative, inter-disciplinary approaches. (More details are given in Appendix D on UNI-SET Energy Clustering Events). This Agenda builds on the success of these innovative programmes and puts forward a set of recommendations and associated framework that will allow all universities to adopt and implement much-needed inter-disciplinary energy work and training.

Specialist knowledge and skills - the core of master's and doctoral programmes, must be supplemented, informed and enhanced by the development of a broad energy perspective. Including technical, social, policy, economic and legal aspects will allow university master's and PhD graduates to understand the wider context of their specialist work. It will also ensure that expertise is effectively focussed on developing solutions to energy challenges - the focus of the SET-Plan. The key need for energy specialisation enhanced by a broader perspective can be illustrated by the recent integration of T-shaped skills into programmes at several universities. The vertical bar of the T represents the depth of skills and expertise related to a specific field, while the horizontal bar represents a more general understanding of other disciplines, creating an ability to work with experts in other areas and apply knowledge in other areas of expertise⁹. For future energy specialists, the horizontal T bar should include opportunities to learn about other technical areas as well as a range of social, economic, regulatory, human and political topics, to provide an understanding of whether and how different technical approaches will be adopted. Social science and humanities specialists (e.g. Market Economists, Lawyers, Political Scientists, Urban Planners) will need to know about a range of technical topics as part of their horizontal T bar. They will also need to learn about views across the social sciences.

These changes will require appropriate support for teaching staff, as many are used to studying and operating within a discipline centric setting. Universities must find ways to allow career development when supporting and encouraging exceeding boundaries, to move this Action Agenda forward. Issues must also be considered in the short and long term, considering geographic factors such as local requirements to reflect the evolving and often local nature of our energy systems and the scale of current and future challenges.

The social sciences have widely ranging views and perspectives on energy and conceptualise energy issues in fundamentally different ways to those often found in technical/scientific contexts. An awareness of these different views is essential. Equally, social science programmes in the fields of energy, climate and the environment need to engage with the basic disciplines of science, engineering and technology.

From an educational perspective, there is a pressing need for university learning, teaching and training approaches to keep up with the rapid pace of change. This requires energy programmes to expose students to current thinking, new ideas and new methods, and can be achieved by using the effective approaches advocated in this Agenda:

- More widespread use of case/challenge based teaching including more multi-disciplinary courses and work. Real-life challenges tend to be multi-disciplinary and to cross the boundaries encountered regularly in discipline-based courses. Multi-disciplinary approaches bring groups of students with different backgrounds together to understand the various angles from which a specific discipline looks at such challenges. They also help develop inter-disciplinary communication skills.
- Move towards more skills-development based education that uses case/challenge-based approaches, changing the role of teacher to that of a facilitator. This approach guides students on where to look, but does not tell them what to see. Students learn how to find essential, quality information and develop the ability to judge validity. Student paths then develop more around self-study, giving them the opportunity to explore areas of interest in more detail. This approach also aligns well with more open-ended discussions, in which there is no right or wrong, just ideas that can/should be developed sooner rather than later. It also individualises education, which is a challenge many universities are struggling to address in what is currently considered more of a mass-market approach.

The reader may also want to consult the 10 European Principles for the Enhancement of Learning and Teaching produced by the EFFECT consortium¹⁰ and further proposals made here.

2.2. General Principles for the Successful Implementation of the Action Agenda

The following key principles have been identified for implementing the recommendations of this Action Agenda:

- (i) *High-level support* must be in place for these proposals, requiring university leaders/senior academics to champion this new approach. There must also be an institutional commitment to interdisciplinary work across Science, Technology, Engineering and Mathematics (STEM) as well as Social Sciences and Humanities (SSH) subjects. Working successfully across this breadth of disciplines requires a commitment to cooperation, respect for other disciplines and differing approaches as well as a recognition that all parties have a valuable contribution to make.
- (ii) The overall transition requires a culture change that will need to be reflected in university structure. Developing student-centred, challenge-based education will require universities to introduce new structures to deliver programmes. Current university structures can prevent the easy upwards/downwards communication of information. This can also lead to defined roles, which is not consistent with the new approach. The new culture needs to trust employees and allow them to take responsibilities to deal with the issues, rather than to limit them to a set job description. Such changes should also reduce bureaucracy and free time for interaction with students, which is a core university responsibility.
- (iii) Suitable *support and development*, to allow staff to embrace multi/cross-disciplinarity and move towards an inter-disciplinary delivery approach. Change is often accompanied by uncertainty about roles and responsibilities, which will need to be circumvented by training to allow people to grow in this direction, accompanied by reassurance that this is a good path to serve students better and for the future. Failure to provide this support means that existing disciplines are likely to maintain their favoured approach resulting in either a slow, or no transition. The staff development tools required can be developed and shared across universities, helping develop more inter-university cooperation. This does not need to be limited to universities and can involve industry and other partners.
- (iv) The role and contribution of different disciplines needs to be agreed and clearly articulated in order to achieve a coherent programme that meets the core specialisation requirements and is supported by additional opportunities to give breadth and context. This applies equally to core STEM or SSH specialisations. Specific examples and recommendations are presented in later sections. The overall design should produce a coherent programme that flows and has appropriate levels with clearly defined learning outcomes, combining the benefits of horizontal *breadth and contextual* elements. It is a challenge to provide such breadth without losing depth, so careful balancing needs to be performed, but both kinds of programme (more generalist or more specialist) can be offered, so long as both elements are included.
- (v) A variety of *learning approaches* is required. These include: peer to peer learning, experiential learning, digital learning, industrial experiences in other sectors and the opportunity to develop a broad range of professional skills including communication, management, teamwork, interdisciplinary work and the use of virtual digital and data analysis tools. Universities are encouraged to consider new learning models, incorporating digital technologies, virtual learning environments, online training, virtual and blended approaches as appropriate. These should only be adopted where they add value to a programme. Such new approaches should be regularly reviewed to ensure their continued effectiveness. Due consideration should also be given to the most appropriate method of delivering the programme using the most suitable and up to date educational frameworks.
- (vi) *Cooperation with other sectors*, including: industry, policy, NGOs, and other energy-related organisations, should be an integral part of this new approach. Cooperation can be through a range of activities including placements, projects, guest teaching, training, advisory boards, social engagement

and outreach activities. The active and experiential learning provided is an important contribution to skills development. Given the importance of energy at all levels, public outreach and engagement with communities, citizens, politicians and debate should also be an integral part of any energy programme.

- (vii) The continued development of new energy-related professional skills should be a *life-long commitment* to a successful low carbon society. This Agenda's approach should empower continuing professional reflection and development allowing professionals to generate new skills and acquire new knowledge at any stage of an energy-related career. Lifelong learning should therefore be embedded, as some aspects may already apply to energy industry professionals. In some cases, it will be helpful to provide short courses and online training modules for inclusion in lifelong learning programmes. These options could also form a subset of modules for a master's programme (also referred to as a MicroMasters).
- (viii) *New programme design* needs to be in line with Europe's different local energy needs. We have to look at what local markets can provide. For example, marine energy is probably not relevant for a central European country with no access to the sea, but may be much more important for other nations. In many countries, new education programmes are proposed and approved by organisations outside universities, including government departments; so providing a good spread of university programmes becomes an important aspect for new programme design. Developments need to consider local knowledge as well as more widely available expertise. However, a certain standardisation is essential to improve inter-university cooperation and allow students to travel and broaden their horizons, for example through Erasmus programmes. All European universities have signed up to the Bologna agreement, but local interpretations vary, and this needs to be addressed.
- (ix) The most common challenge in moving forward is *communication*. More open, constructive, communication to benefit everyone is essential for any of these changes, e.g. to support cooperation within and across universities as well as with other partners. Improved communication should also help support resource-sharing, avoiding the duplication of work to free time for developing improved frameworks for cooperation and interdisciplinary education and research. Technology helps, but it will be essential to ensure standardisation, at least at European level.

2.3. Master's Programmes

This Action Agenda advocates repurposing and refocusing energy-related master's programmes on the global energy challenges set out in the SET Plan. Challenge-based master's programmes that focus on developing robust, coherent and holistic energy solutions, shift away from the more common focus on a single energy technology, or group of energy technologies that only cover part of the energy system. As explained earlier, adapting master's programmes to include an integrated energy system perspective will enable students to make a more substantive contribution to the search for energy

solutions. The kind of master's programmes advocated here will provide detailed, comprehensive, state-of-the-art knowledge in a specific area as well as significant training and skills for a career in the energy industry. While master's programmes across Europe still vary in length, skills development is most effective over an extended period, giving students time to acquire skills, reflect and refine their approaches.

Employers value projects focussed on problem-based or challenge-based learning, particularly those that address real economic and business issues and include social/human contexts (e.g. ethics and user interactions). Practical or applied experience is often seen as more important than a student's academic achievement. Industry is also keen to employ graduates with the ability to be flexible and switch fields.

Generally speaking, master's degrees are awarded to students who demonstrate:

- Systematic understanding of a specific field of knowledge, critical thinking, analytical awareness of current problems and new insights to address these problems. Much of this understanding is informed by, or at, the forefront of the field of study.
- Wide-ranging and comprehensive understanding of the techniques used in their area of study.
- Originality in applying their knowledge, together with a working understanding of how established research techniques are used to create and interpret knowledge in their field.
- Conceptual understanding that enables a critical evaluation of current research and methodologies in their field of expertise.

(This is a synopsis of The Frameworks for Higher Education Qualifications of UK Degree-Awarding Bodies¹¹. Further examples of European Qualification Frameworks can be found on ENQA¹²)

New energy-related master's programmes should include contextual and background material that expose participants to the full breadth of the energy challenge in addition to their chosen field of study. Both aspects need to be carefully balanced so as not to compromise the core skills required. Programmes should be designed to give students insight into the complexities and interconnected nature of the energy system and our societies deeply embedded and constantly evolving relationship with energy. A key aim of providing such background information is to allow students to understand how their master's programme specialisation fits into the energy landscape. It could be implemented in a variety of ways, for example, a 4-6 ECTS (online) course giving the tutor flexibility to emphasise specific key concepts. It is important to combine background information with more specific master's programme topics, and to set these in the context of locally available/possible energy systems. Care must also be taken to ensure that additional components are not too onerous. The outcome should be a coherent programme that includes complementary topics to provide context, breadth and background knowledge for particular specialisations.

The generic/specialist split could range from 50/50 all the way to 20/80 to create a variety of different master's programmes that fulfil employer needs. Universities are not required to launch additional pure or generic courses but to include project work, industry

cooperation, case studies or workshops to integrate interdisciplinary aspects into existing curricula. Generic topics should only be covered at a more superficial level of understanding/appreciation, as opposed to the in-depth detail usually expected from master's students. This can easily be achieved through e.g. case/challenge-based projects. It is also reflected in the table in Appendix A, which includes guidance on expectations for generic and detailed learning in master's programmes, for technical, as well as economic, social and political subject areas.

Section 3 gives specific examples for 3 of the principal SET-Plan areas: (i) *Energy Efficiency*, (ii) *Smart Grids and Energy Systems* and (iii) *Renewables Integration*. These examples have been developed by energy experts across Europe and are based on the following general principles.

General Principles

The first set of suggested topics in Appendix A are grouped to emphasise the technical aspects of the energy system. Here, we need to consider that while there are more specific master's programme topics, there is also a need to cover more generic subjects to give students an overview of the entire energy system. This applies to energy related topics, regardless of whether they have a more technical, social, political, or economic focus.

Consider the most relevant generic topics from the table, then focus on the left-column covering the basic understanding required. While some of this may and perhaps should have been covered at bachelor's level, not all master's students have the same background, so it is a good idea to cover generic areas as widely as possible. This allows students to appreciate, e.g. how the various generation technologies operate, their respective advantages and disadvantages, how renewable generation tends to need energy storage and its challenges. Students must have a basic understanding of the key challenges of central energy generation and distribution to the point of use as well as the interactions between energy, transport, food, water and so on. Many of these topics require further research, which is a source of project opportunities for master's/PhD students.

The level of coverage of social, economic and political elements has again been divided into basic and more detailed knowledge, where the latter targets master's students. The table in Appendix A tends to cover information at a more generic level. Individual expert teachers are expected to develop these general guidelines into a more detailed programme for their specific context. However, aspects like how the energy markets work, how social acceptance of technology can be improved, political influence (e.g. regulation and taxation) and so on, are all important and should be addressed. These can be included in case-based teaching.

2.4. Doctoral and Research Programmes

Doctoral programmes are distinct from other academic programmes as they involve original research in a specific area to generate new knowledge, new understandings, new insights and new approaches. This qualification is awarded through the process of conducting research, analysing and reporting the findings. Doctoral programmes also equip PhD holders with a broad range of advanced scholarship, research, analytical, communication and other professional and

transferable skills that are highly beneficial for energy careers.

Doctoral candidates have the skills needed to develop creative and novel solutions to complex problems¹³. PhDs are generally awarded to students who:

- Create and interpret new knowledge through original research and/or scholarly activity that is of sufficient quality to satisfy peer review, extends the forefront of the discipline, and merits publication.
- Demonstrate systematic acquisition and understanding of a substantial body of knowledge at the forefront of an academic discipline, or in an area of professional practice.
- Have an advanced ability to conceptualise, design and implement an original research-based project to generate new knowledge and cutting-edge knowledge application, including the ability to adapt the project to unforeseen problems.
- Possess a thorough and detailed understanding of the methods and techniques needed for research and advanced academic enquiry.

(This is also a synopsis of The Frameworks for Higher Education Qualifications of UK Degree-Awarding Bodies¹⁴. Further examples of European Qualification Frameworks can be found on ENQA¹⁵)

The EUA Council for Doctoral Education (EUA-CDE) recently published a new set of recommendations: *Taking Salzburg Forward – Implementation and New Challenges*¹⁶. These recommendations set out guidelines for the strategic reform of doctoral education and continuous strategic development. The concept of structured doctoral education and schools has been widely introduced and is recognised within the framework. Recommendations include a consideration of ethics, digitalisation and globalisation, which are increasingly important in all doctoral programmes. The proposed reforms to make doctoral support structures more coherent and enable ownership by all parts of the institution are key and should be considered integral to this document, but are not its core aim.

Successful 'doctors' can make informed judgements on a range of complex issues in specialist fields like energy, using innovative approaches. This requires initiatives, often through autonomous actions in complex and unpredictable environments in which data and information may be incomplete. This Action Agenda argues that including contextual information about the full scope of the energy system in doctoral training will significantly enhance the effectiveness of doctoral candidates. Additional breadth will allow them to ensure that their proposed and applied approaches lead to durable, sustainable and effective solutions to our energy transition. Doctoral programmes could be based on the T-shape model drawn from good practice, such as industrial economy programmes combining mechanical engineering with economics. Here, the vertical column of the T addresses the core research topic, specialist expertise and skills required, while the horizontal bar addresses fundamentally important knowledge from other disciplines essential for understanding the challenges faced as part of the energy transition to a low carbon society. The horizontal component goes beyond the concept of 'general skills' under *Taking Salzburg Forward* included in many doctoral programmes (i.e. that address research ethics, communication skills, engagement with civil society etc).

Crucially, horizontal components must engage and be attractive to academic staff across all disciplines to ensure their quality, recognition and merit within the university faculty and department

structures and their quality assurance processes. The horizontal bar must not be too long or too generic. Doctoral theses must at least clearly understand and state where industrial/economic/social needs lie and which potential applications could therefore be produced. National and European funders of doctoral research increasingly require PhD candidates to pay more attention to the potential impact of their research not simply in terms of the technical and/or market and/or academic field of application, but also in terms of wider social impact. Such increased attention to impact will need to be considered when developing new doctoral and research programmes. The recent Lamy report¹⁷ on maximising the impact of EU Research and Innovation Programmes provides more information.

From the T to an A and/or Q-shaped model

The T model could evolve into an A and/or Q-shaped model. Each supports the need for combining essential research knowledge in core engineering or technical disciplines with the broader perspectives of context and impact to support the energy transition. In this context, the A-shaped model represents where one core discipline merges with another discipline at the apex to form a new discipline with defined theoretical foundations. The horizontal bar of the A includes necessary components from other disciplines that provide the knowledge required to tackle the broader context,

e.g. climate change, demographic change, citizen behaviour/input, political and economic factors, governance and regulation and foresight about future technology and society.

The Q-shaped model builds on the fact that doctoral candidates should be well-rounded individuals - represented by the circular part of the Q. They are at home and comfortable talking and thinking about the context and impact of their work and communicating this in a variety of settings, beyond their own specialisation. The bar of the Q represents the fact that they have wider/deeper expertise in their field of study. This field can expand further, be positioned anywhere on the circle or move around as their career progresses.

Achieving such doctoral programmes requires substantial dialogue and cooperation within a university, but once established these innovative programmes will be enhanced greatly by inter-university cooperations at national, European and international level. Cluster events held under the UNI-SET FP7 coordination action have already demonstrated a potential for innovation that needs to be encouraged and developed.

Cooperative doctoral programmes will present broader contextual issues in more detail and with more synthesis between complex, differing scientific, technical and social factors.

3. Examples of Future Challenges and Opportunities in Energy Research, Innovation and Education

This section discusses the ideas and framework presented in the previous sections in more detail for 3 technologically important areas of energy research and innovation, which are also key SET-Plan areas, namely:

- Energy Efficiency
- Smart Grids and Energy Systems
- Renewables Integration

More detailed descriptions are given on how to apply the general principles described earlier in each of these areas and their respective contexts. There are obviously many other areas to focus on when developing new programmes. These are to be seen as examples demonstrating how the generic principles explained in the previous section can be applied and are not the only topics that need to be covered.

Each of the following examples starts with an indication of the current state-of-the-art, before describing the key topics to cover in master's and doctoral programmes. The state-of-the-art sections are to be read as key trends, not detailed descriptions, as defining the state-of-the-art is challenging in constantly evolving fields.

Please note that further details on items including anticipated learning outcomes and skills gained are available in Appendix A. The table contained in Appendix A clearly distinguishes between what students should appreciate at a basic level, and/or fully grasp in detail. Each of the 24 topics provided is split into technical, social, economic, and political subjects, as well as soft/employment skills, to give a complete overview of what should be delivered in this context. This table can be used as a guide to ensure compliance with the various aspects stated in this document e.g. multi- and inter-disciplinary education. Experts are to use it as guidance to ensure they cover the essentials, while completing the details for their local setting. The following sections indicate the important topics for a specific programme that should be covered in depth. Examples of innovative ways of delivering some of the content in these courses are provided in Appendix B.

3.1. Energy Efficiency

3.1.1. State-of-the-Art and Current Trends

Increased energy efficiency is a cornerstone of 2020 and 2030 EU energy strategy. This is because improved energy efficiency is key to reducing greenhouse gas emissions and securing Europe's energy supply, as well as to reducing costs, stimulating employment and improving quality of life. One of the three targets in the 2020 strategy defined by the EU is a 20% increase in energy efficiency

(from 1990). This target is not an end-point but a stepping stone to further improve EU energy and emissions, as seen in the 25% efficiency improvement target in the 2030 Strategic Framework¹⁸. Substantial energy efficiency improvements will unquestionably continue to be a challenge across all sectors, including energy production, distribution and consumption in industry, buildings, transport, agriculture and services, for many years to come. To achieve this goal, research is needed to further develop and design new energy efficient technologies and materials while simultaneously developing a strategy for getting them to be accepted on the market.

European universities have long-recognised the pivotal role of energy efficiency, as shown in the UNI-SET survey¹⁹, where energy efficiency in industry, services and buildings is one of the highest scoring topics covered by energy master's and research programmes. Smart city topics also rank highly, and while they do not specifically address energy efficiency, they are related due to their sociological and technological similarities.

Energy efficiency is not generally a single technology issue (like solar or wind power). It cuts across different sectors and technologies requiring interdisciplinary and systemic approaches. Increasing energy efficiency is common to all energy professions. It is especially important to stress that energy efficiency goes along with the application of renewable energy targeting near or net zero emission systems (in particular in buildings), as energy efficiency is a prerequisite for practising renewables:

- i) The cost of saving a kWh is often less than that of producing a kWh using renewable sources. However, this clearly needs to be evaluated on a case-by-case basis, to draft suitable conclusions and solutions.
- ii) Unlike renewable generation, saving energy aids continuity/reliability by reducing demand.
- iii) Reduced energy demand also reduces the amount of energy supplied by both fossil and non-fossil fuels, including renewable sources. This reduces the need for large generation and storage infrastructure and capital investment and maintenance costs.

Teaching energy efficiency should therefore be a core topic in any curriculum involving energy technologies and/or the socio-economic aspects of energy.

To be effective, measures to improve energy efficiency must always be seen in a systemic, inter-disciplinary context that includes a product/service life cycle within a local/regional energy system including end-users. We can either reduce the energy intensity of a product/service and/or increase the economic and/or social benefit obtained per unit of primary energy, e.g. using waste heat from industrial sites within a circular economy to improve energy efficiency. However, increasing the energy efficiency of a single process or technical element is much less effective than reducing energy resource consumption and emissions across the whole. Finally, energy efficiency improvements in technologies and processes should be spread among and adopted by the largest possible community of end users.

3.1.2. Master's Programmes

Master's programmes lay the foundation for future leaders and experts, so it is important that energy efficiency issues are the focus, but it is also essential for all programmes to include generic aspects. The proposed structural approach shown in Figure 1 is designed to achieve both targets. It builds on the principle that everyone should be familiar with common interdisciplinary content, after which other shared topics (methodologies and technologies, in that order) are provided in line with the master's programme topic, and finally the most specific content is delivered in more detail.

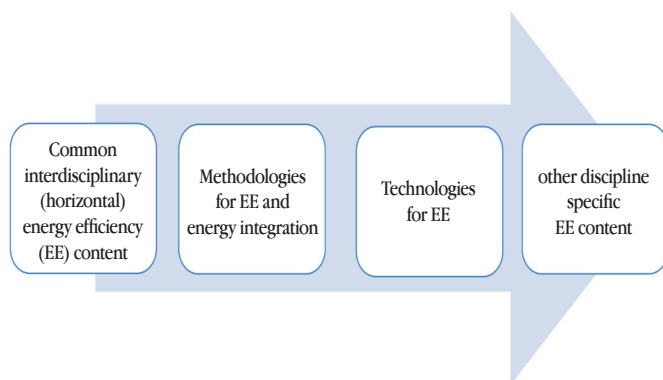


Figure. 1: Timeline showing the typical contents in energy efficiency master's programmes

As discussed earlier, energy efficiency issues must form an integral part of any master's programme for students wishing to plan and operate industrial sites and/or buildings. In addition to the general energy-related components defined earlier, a fraction of the methodologies and technologies curriculum should be dedicated to energy efficiency modules. At least a generic understanding of some of the following topics from the table in Appendix A should be covered: *System Simulation/Modelling, (Renewable) Technologies / Energy Sectors – All, Energy System Control, Technology Use, and Building Design*. Additionally, certain topics like energy efficiency, need to be covered in much more detail. Note that these generic elements do not need to be provided as stand-alone courses – they could be integrated in other parts of the curriculum dealing with related issues. Examples of how areas can be combined to cover the essential elements in a master's programme can be found in Appendix B.

3.1.3. Doctoral and Research Programmes

At doctoral level, the interdisciplinary and transdisciplinary integration of different players needed to achieve systemic energy efficiency should take precedence. Course elements must complement knowledge acquired at master's level, to ensure that all doctoral candidates in energy-relevant disciplines have a fundamental understanding of:

- Energy efficiency technologies and planning methods in industry and buildings
- Stakeholder interaction (consumers, prosumers, investors, etc.) for systemic energy efficiency

- Social and behavioural aspects of energy efficiency

Overall, the following are considered important research subjects:

- *Energy efficiency planning method repository* – Many different planning methods are used in different disciplines and at different levels. No comparative study on the optimal application for each and their value to the parties involved is currently available. The potential benefits of combining planning methods also need more thorough research.
- *Total energy requirements* – European industry is a major energy consumer. Increasing the energy efficiency of industrial systems and outside factory gates (e.g. local and regional energy systems) is a major field of research for better energy efficiency. Transport is also a major energy consumer and while the efficiency of a particular mode of transport (land, air, water) is often examined, little work considers the optimal combination of these different modes.
- *Model collaboration* - Many scientists acknowledge that the best model classes should be combined for a new and more integrated approach to modelling, namely: model collaboration. Models do not need to be larger and/or more complex. By using model collaboration, different approaches and tools can be combined.
- *Socio-technical transitions* - Meeting EU energy efficiency goals will require the transformation of our entire energy system from how energy is produced, distributed, and consumed to how the various sectors use energy and interact within and with each other. Accomplishing this requires an understanding of how such transitions occur, the identity of the players and how they are connected in the larger value chain (e.g. property owners versus residents). It also requires research into how innovation can create technological niches for energy efficiency, and how these then penetrate the larger socio-technical status quo and transform the energy system.
- *Rebound effect* - Any energy efficiency initiative must also include mechanisms and strategies to understand and counteract the rebound effect or Jevon's paradox. Behaviour analysis and incentive structures need to be identified to give a better understanding of how efficiency improvements relate to improvements in quality of life, and how to make the most of a utility using the lowest possible level of end user consumption.
- *Efficiency gains across energy vectors* – Most current work studies efficiency within a single energy in detail. However, the opportunities can lie in combining different energy vectors (electrical, heat, etc.) and then calculating conversion efficiency.

3.2. Smart Grids and Energy Systems

3.2.1. State-of-the-Art and Current Trends

Although Smart Grids have become a common concept, we are still defining what smart really means - the concept expands continuously. 'Smartness' is obviously closely related to Information Technology (IT) developments like Internet of Things (IoT), Artificial Intelligence (AI), etc. These have been the driving force behind smart technologies and are therefore also key to further developments in these and related fields. In the energy sector, the initial drive towards a Smart Grid came from the growth in small, distributed energy generation combined with an interest in achieving high levels

of self-consumption or local consumption of that energy. This meant that the grid moved away from its previous hierarchical structure. Additionally, an interest in improving energy consumption by consuming when low-carbon energy is plentiful and/or exploiting the flexibility of some consumption to provide services to the grid as a whole catalysed smart grid development. Consequently, the current smart grid context involves finding a means to identify and use new flexibilities in generation, consumption, storage or network assets to manage the electricity grid, while recognising that the traditional flexibility of fossil-fuelled, central generation is not as available as before. However, the concept of smart grid development can also embrace the move towards smart metering and the reduction of unnecessary AC/DC conversions in generation and consumption by introducing DC distribution networks. There is an increasing trend towards a network of different networks and even different energy types (electrical, heat) that need to be interconnected and need to communicate with each other to deliver an optimised solution, to ensure resilience.

One of the main aims of all these changes is to find better ways to match generation with consumption, especially as renewable-based generation is available intermittently, uncontrollable and therefore unable to track demand. This has created interesting challenges for timing, prediction and storage - being able to predict renewable output is particularly important for demand planning. This planning needs to be able to span scenarios in different time horizons. It is also increasingly apparent that treating demand as inflexible and arranging for it to be met over-constrains the problem and fails to recognise that some demand is discretionary and can be delayed and/or advanced. This requires a better understanding of the demand for services and its implications for energy use. It also implies that innovative services that allow consumers to benefit from consuming flexibly will be needed alongside new regulatory or market structures to facilitate them. Consequently, there will be many more active participants in the energy system and a wider range of control services, requiring coordinated local, regional and national objectives for matching demand with supply and security of supply, including the control of distributed (local and more central) energy storage facilities. In this context, it's important to note that energy services and demand can build on the principles of e.g. heat storage in buildings and exploit Vehicle to Grid (V2G) approaches resulting from the electrification of transport.

The move towards carbon-neutral energy generation that matches demand has made clear that systems can no longer operate in isolation, but have to be combined into a system-of-systems, that preferably function without the need for a human operator. This approach should not be limited to a single energy vector, as including an ability to convert between energies to handle e.g. peak demand can increase energy efficiency. This holistic perspective supports efficiency and justifies the introduction of e.g. district heating grids, which help balance the entire system. The inherent heat storage capacity of buildings makes it easy to envisage an ability to improve the balance of demand and generation in time.

An important feature of electricity grids in developed nations has traditionally been very high reliability. This was achieved by providing redundancy in grid assets (alternative supply paths) and

generation assets (standby and reserve generation). The solution needed to continue this approach while replacing (flexible) fuelled generation with (less controllable) low-carbon generation would be costly. While a smart grid covers the principle of a secure supply by fast deployment of technologies such as storage, demand response or e-mobility, the nature of the risks in the system has moved. The drive to balance everything automatically using a set of interconnected systems has introduced new risks like security and reliability. For example, an energy system can be developed for a 10, 20 or even 40-year lifespan, but there will be many versions of an Operating System (OS) over that time, with predecessors often no longer being supported. An inability to upgrade to the latest OS often results in serious operational security issues, and while these could be prevented by disconnecting the system, that would disrupt the entire system-of-systems approach. This trend enforces updates, which can be hard to implement in continuously running systems and may also introduce (new) reliability issues. While such continuous updates may be essential, they are not necessarily beneficial. Therefore, it is essential to consider these elements from the very start of the design process, to focus on solutions that provide appropriate reliability, security, resilience etc.

While much of the above refers to the need to replace existing equipment with new equipment, we need to remember that a detailed life-cycle analysis of current and planned equipment is essential to understanding full environmental impact and to avoiding any unnecessary damage. This includes a need to examine material choice and identify the most suitable, most low-impact materials for proportionate life cycles that are preferably much smaller than planned length of use. Holistic planning also needs to avoid thinking of the status quo as the standard for years to come, and to consider radical changes to e.g. demand and the energy market, in terms of what the future may bring.

3.2.2. Master's Programmes

The very varied challenges in smart grids and energy systems require a varied skill set. Individuals must possess a broad general knowledge to, e.g. appreciate impact and context, while also being able to focus on the details of a very specific topic such as smart meter communication requirements and allowing the smart grid to predict and match demand.

If we were designing/delivering master's programmes on smart grids and energy systems, we could focus on any of the related topics mentioned in the table in Appendix A: *Energy Infrastructure – Smart Grids – Distribution Networks, (Renewable) Technologies / Energy Sectors – Chemical*, and either combine these, or explore a specific field, such as solar, or wind in more detail to focus on a specific type of system. However, the more detail provided on a specific topic, the more likely the generic aspect essential for creating a functioning system-of-systems will be overlooked, so we need to seek a suitable balance. For example, it is important to touch on the generic aspects of urban or ocean-generation planning in a course on wind turbines, as planning permission is usually required. This balance can be achieved in a variety of ways, e.g. using project/case studies within courses or across the programme to unite different subjects. Examples of such approaches are given in Appendix B.

In designing a new programme, it is important not to overlook the following elements of the energy system:

- Energy system boundaries and the hierarchical location of system-of-systems linking a network-of-networks. An appreciation of the energy system, how generation and load can be balanced, and the effect of combining/converting between and embracing different energy types is required. It is important to maintain a holistic perspective to achieve optimal system operation by integrating/using the most relevant energy vectors and capturing their interplay.
- New systems need to be designed to function for a long time, using materials that minimise life-cycle considerations. While these new systems need to be integrated with existing/current technologies, they will also need to be integrated with future technologies. Long-term vision must be imparted to ensure that all energy systems are designed for the future. Reliability, security and energy efficiency/savings must be key aspects of any design, prominent from the start. Customers must be given a central role, triggering significant differences in requirements, for example the need for various technologies to serve different needs and e.g. allow customers to become self-sufficient.
- The more generic programme elements should enable understanding of the need to change not only in technical terms, but also in culture, business models, the economic context and so on. On the other hand, cross-disciplinary subjects need to be taught from a technical angle, so students appreciate why these modules are included. Topics such as: social responsibility, the need for (re)building communities, privacy versus efficient system control, local decision making versus central coordination etc. need to be suitably covered. Moreover, relevant new technologies and markets (5G, e-mobility, prosumer aggregation, inertia-less systems) should be addressed and emerging concepts (e.g. cell-based approaches, energy communities, energy harvesting, distributed storage, etc.) investigated.
- Energy has a very strong social aspect, involving building energy communities to support decentralisation, while instilling responsibility about consumption and teaching awareness of the socio-economic impact of decisions like demand driven response. After all, the purpose of technology is to aid humanity, and avoid detrimental effects like enlarging the gap between rich and poor. Past research has shown that policy can have a particularly important influence on technology developments and integration, e.g. Photo-Voltaic (PV) technology. The ethical implications of integrating technologies such as smart metering and its impact on user behaviour, especially when this results in pricing changes and could drive more people into fuel poverty, are important.

3.2.3. Doctoral and Research Programmes

It is essential to distinguish between applied and basic research programmes. While often less considered standard, basic research should also be inspired by real-life problems. While there is clearly a need for both types of research, impact and context depend on the type of research. For example, it will be much harder to describe the short-term impact of basic research, as this is normally more influential in the long term.

In practice, every dissertation should include a section/chapter focusing on the context and impact of the research carried out. This section may be shorter in basic research theses and would be more focused on potential long-term impact, whereas for applied research this section should be larger and examine the context and impact of the research topic. While there are obvious differences for each individual project, the aim is to ensure that part of a PhD study leads the candidate to adopt a well-rounded approach that appreciates the e.g. social, economic, political, environmental, aspects of their work. This skill will also be essential at many stages in their career, e.g. when taking their research forward through grant applications. If dissertations cover a wider perspective, it will be easier to share them with other fields of expertise, where readers can start from the more generic aspects and obtain an understanding of more detailed perspectives.

There are many key research topics that need investigation, as may have become apparent. There are obviously many challenges involved in the smart grid: decentralised locations, energy storage, the creation of autonomous system-of-systems, long-term reliability and security, to name a few. We need to examine how systems will be integrated with other systems, analyse their life cycle and the materials used to construct them, the challenges for interactions between new and existing systems as well as their individual and overall sustainability.

3.3. Renewables Integration

3.3.1. State-of-the-Art and Current Trends

The transition to a low-carbon society is largely dependent on the successful integration of energy from low-carbon, renewable sources. Significant progress is required to meet 2020 and 2030 EU Energy Strategy targets.

The UNI-SET University Survey and Atlas²⁰ have identified a broad range of master's, doctoral and research programmes in all renewable energy technologies (e.g. Solar PV, wind, geothermal, hydro, wave, biomass etc). To achieve the Integrated SET Plan²¹ ambition for an Energy Union that's number 1 in renewables (RE), it will not be sufficient to only have highly efficient low-cost technologies for RE-based electricity. They must also be successfully integrated into the energy system, "to sustain technological leadership by developing highly performant renewable technologies and their integration in the EU's energy system"²². 'Renewables' Integration' does not mean treating the energy system as including different components, but more specifically about fully and effectively integrating RE technologies in a way that maximises their contribution to meeting our energy needs.

The developing concept of Energy System Integration is obviously an important aspect for integrating renewables. Energy System Integration (ESI) is defined as: "the process of coordinating the operation and planning of energy systems across multiple pathways and physical scales in order to deliver reliable, cost effective energy services with less impact on the environment" (iiESI, International Institute for Energy Systems Integration²³). It

is internationally regarded as a key emerging approach in energy research and industry, as demonstrated by: (i) the creation of the US industry and iIESI National Labs, and (ii) the new European Energy Research Alliance Joint Programme in ESI²⁴. Energy system integration recognises that sustainable, long-term solutions to meet energy demand require a holistic approach effectively integrating a range of different energy technologies. One major challenge is the need for efficient interconnection between established, ageing technologies and new, renewable technologies to achieve an efficient energy system from production to user, and across all energy carriers. The challenge for micro-grids or emerging energy communities is to integrate all new technologies. A critical issue involved in the greater use of renewables is that they are intermittent - greater emphasis needs to be placed on appropriate energy storage. These technologies also struggle to maintain the inertia in energy systems as they are not generated kinetically.

Renewables offer an opportunity to embed distributed sources into existing energy infrastructure, which is increasingly seen as a more flexible alternative to large centralised electricity generating facilities. However this does not alter how energy is delivered to end users, and changes to the existing hierarchical structure will become essential. Distributed, multi-source generation raises complex multidisciplinary questions about technical, environmental, economic and social issues. There are also interesting challenges for local generation and use versus energy 'sharing' across local and national boundaries.

While many believe that the aim is to achieve 100% renewable sources for energy generation, the route from our existing energy generation and technologies network to this bold new world will be complex, partly due to the different and evolving levels of contribution from current technologies and more sustainable and renewable approaches. A broad range of technological improvements will be required en-route. Successful integration of renewable sources will also partly depend on our ability to continue to improve the efficiency of all current and future technologies in the energy chain. Due to the complexity of each of these problems, energy system professionals will need a broad understanding of many renewable technologies, their current and future potential and a sense of how each can be developed and brought together as a holistic system.

In this context, economic and energy policy frameworks also exert a considerable influence on the impact of energy technologies. In the past, this was often overlooked, but a review of the deployment of, for example, solar PV/thermal in Europe confirms that actual integration was driven more by economic and policy frameworks than by technology improvements. The scale of the challenge for the 2020 and 2030 timeframe confirm that technological improvements will have to be accompanied by effective economic and policy frameworks that engage and incentivise societies to adopt new renewable technologies.

3.3.2. Master's Programmes

Master's programmes in Renewables Integration can be grouped into 4 general categories:

- a. Those that focus on a specific renewable technology, e.g. wind energy, etc.
- b. Those that focus on the grid, where renewable sources are an interesting and significant contributor
- c. Those that focus on application in a specific sector, so on actual integration in practice, e.g. buildings with integrated PV
- d. Those providing a wider overview of a technology, e.g. thermo-technical conversion

System and integration aspects are currently often missing from these 4 different master's programme types, although as noted above, they need to be included. The basis of a master's curriculum in renewable energy integration should allow every student to know how different renewable sources interact with the energy system, with society and the wider environment, and where their specific focus fits in the energy system from both a technical and social perspective.

The main components of a master's curriculum on integrating renewable energy sources should cover the following generic elements (for further details see Appendix A, detailed examples on achieving multi-disciplinary aspects are provided in Appendix B):

1. An overview of renewable energy sources including a comparison with non-renewable energy sources. The basic working principles of these technologies, their intermittent and situational characteristics, potential contribution, respective efficiencies and future potential.
2. How renewable energy sources interface with the energy grid and other energy systems, considering the factors that affect their efficiency. Approaches that maximise the contribution of renewable technologies, minimise associated carbon emissions and optimise life cycle considerations.
3. Recognition that society tends to consider energy services as more desirable than energy itself - the social value of what energy can achieve is higher than its intrinsic value. This energy-service approach generalises energy as a demand that needs to be met using renewable energy to minimise environmental impact. This requires an understanding of how different forms of energy are used and their respective value to society.
4. Knowledge of the different energy networks and vectors to which these renewable energy sources are being connected. This should include an understanding of the usability and management of different energy vectors, such as electricity, fuels, heat and hydrogen; to give master's students a basic knowledge of how energy systems influence energy flow.
5. Energy system interaction to balance production with demand, across time and geography. Students should also appreciate the importance of new, reflexive and autonomous approaches to controlling energy flows. Micro-grids offer a viable alternative in certain circumstances and these contexts should be understood. Different energy storage and buffering options for different energy vectors. The characteristics of these energy vectors, including capacities, efficiencies, the importance of the rate of charge/discharge and network location to make students aware of their potential and the numerous challenges of including them in the energy network.
6. Any energy related master's programme must also consider the economic, social and political factors influencing energy. It is therefore important to consider the role of society and citizens

in the take-up of renewable energy solutions. The appreciation of these perspectives helps develop a better understanding of the limits and constraints of any technological solution and its integration. This includes public perceptions of energy, energy practices, energy choices, prosumers, energy dialogues, and the differing ways in which energy affects different constituencies. An overview of energy economics, including energy markets, energy poverty, ownerships, system service and regulatory costs should also be covered.

While all programmes have more specific elements, more generic elements will also be included. For example, those undertaking a master's programme in engineering or physical sciences will obviously examine a specific technical/scientific area in more depth, but more generic elements will also need to be covered, e.g. through practical case studies. This could be achieved using campus facilities as a living lab to collect and share data among students. Traditional labs and field trips should also be revised to ensure they serve all aspects of the challenges of renewables integration.

The benefits of this new approach are wide ranging. For example, after taking this kind of master's programme in renewables integration, students will be able to discuss and answer the following questions in an informed and insightful manner:

- Who are the key stakeholders in the integration of a certain renewable energy technology?
- Which (combination of) transport is more sustainable for a particular user/scenario: land, air, water and vehicle fuel type: electricity, hydrogen, biofuel, etc?
- Which combination is most beneficial on a given surface (km²): solar panels, wind turbines, a bio-crop field, etc?

Giving graduates a holistic perspective will ensure that they can make a broader contribution to society.

3.3.3. Doctoral and Research Programmes

Doctoral studies require a focussed research programme designed to develop new knowledge and understanding in a specialist field. As a result, doctoral programmes addressing the integration of renewable energy sources must primarily focus on a specific issue.

*The UNI-SET Universities Survey*²⁵ revealed that existing programmes mainly focus on developing new technology, for example a new type of more efficient and sustainable thin-film solar cells, and that very few programmes include system-oriented activities. This should be overcome by including minimum system-level knowledge as part of the PhD curriculum. Consequently, the framework combining specific and generic knowledge also applies. This framework adds value to doctoral research studies, as it gives students greater awareness of how individual research projects contribute to the energy system. They should be able to demonstrate this knowledge by answering key questions framing their PhD research focus: Where does this topic fit? When does it come into play? How does it interact with the system and society? Who are the stakeholders and what is the best business model for deploying the technology researched? The general or specialist nature of the answer to these questions will depend greatly on the research topic. However, there is value in all doctoral candidates being able to provide at least a general answer to these questions, particularly as the SET-Plan is a vehicle for achieving the aims of the Energy Union.

The UNI-SET Survey also identified a good spread of research topics across different renewable energy technologies. These activities should continue as Europe currently leads the world in many areas of renewable energy technology research. There are also considerable opportunities to expand the scope of research areas and topics to include more on how these technologies can be efficiently integrated into the existing energy setting. Modelling and expanding on these new integration strategies and their implications for future renewable energy technologies is also valuable. This work should link up with emerging European financial models and policy instruments. This multi-/inter-disciplinary approach also provides significant opportunities for new cooperations at many levels, including within an institution, connecting scientific, engineering and social science researchers and networking doctoral candidates. There are numerous opportunities for cooperations within new university groups, between universities and industry, and with other sectors. All these help ensure that the future workforce embraces the more multi-disciplinary, holistic approach essential to achieving the successful integration of renewable technologies.

4. Taking the Action Agenda Forward

Successful implementation of actions to achieve the approach to energy education, training and research set out in this agenda will require significant effort over an extended period. While this document is primarily aimed at universities, other key energy stakeholders, such as policy makers, industry and society all share the responsibility of working together to achieve the anticipated outcomes.

The first steps to take depend on where a university is positioned on the developmental path described, and will also differ under the impact of locale on programme development, cooperations and available resources. Some universities have existing energy programmes along the principles outlined in this document, in which case it is hoped that these universities will continue to develop these programmes and will engage with the UNI-SET project to share good practice and provide successful case studies.

One of the key factors for progress is more cooperation. Success will require cooperation within universities, between different universities, between universities and industry, between universities and policy makers, and between universities and societies through outreach. This will require a common, shared university vision supported by senior academic leaders and the staff responsible for developing and delivering the teaching and research programmes advocated in this agenda. This common vision should be developed through cooperation to ensure that all parties benefit. The proposed changes to university structures should also help them become more flexible to address the challenges related to cooperation and the need to develop at the pace of society.

The opportunities for postgraduate cooperations between universities are practically unlimited. The following therefore only describes some scenarios for energy-related cooperations between universities and stakeholders:

- *Living labs & municipalities* - Urban centres and other communities can serve as a test bed for new technologies, processes and strategies and help municipalities deliver better services.
- *Lighthouse cities* - Large scale implementation and road map development explored through cooperation with partner cities.
- *Energy system/efficiency companies* - Cooperation with companies that design, manufacture, and/or market energy products and services could lead to higher quality goods and more market penetration. It would also allow students to transition easily from academia to the private sector and for the private sector to recruit well-trained employees.

This agenda challenges some long-standing approaches - to achieve change universities cannot carry on doing the same thing. It also raises important questions about how experts from different disciplines can work effectively together towards a shared goal. For example, it requires universities to place more emphasis on the development of skills and training in addition to specialist academic knowledge. New learning approaches must be embedded in new programmes through the appropriate integration of learning technologies and other approaches that focus on students and use more challenge-based approaches.

Universities have a unique responsibility to bridge the gap between advanced research and education, for students and other actors who contribute to the transition to a low carbon society. *The SET Plan Roadmap for Education and Training* highlights the need for continuous professional development and to provide workers with a suitable background in the energy area relevant to their profession, while also providing them with the more holistic perspective needed to help them apply newly acquired knowledge, through e.g. interaction with people from different backgrounds or areas of expertise.

Universities are encouraged to consider the different opportunities created by this agenda, not necessarily just for master's and doctoral programmes. This includes thinking about lifelong learning as well as bachelor's programmes and pre-university education. The changes proposed for universities will benefit from a different profile of student intake, so these changes will need to reflect down towards primary and secondary education. This can be achieved through suitable cooperation with both local government and schools. Universities also have an important role to play in providing suitable training for schoolteachers and vocational training institutions and disseminating state-of-the-art knowledge of energy measures to key educators and effectively training-the-trainers. Such activities will further support cooperative links between universities and other energy stakeholders.

To aid the development of these new programmes, a course module repository that can be used for distance learning and sharing good practice across European universities and institutions in other developed/developing nations would be useful. A comprehensive repository of modularised distance learning material dealing with energy issues set out in the Framework Table in Appendix A, would be a valuable resource for use within an institution as well as for sharing more widely.

To achieve the cooperation required at European level, it is important to establish a university energy network to further refine and implement this agenda through discussions, sharing good practice and case studies. The UNI-SET project team will therefore continue to advocate continuing reforms to university programmes in line with this agenda. An important aspect will be continuing to provide an independent, university perspective for energy policy and position papers.

Universities are strongly encouraged to maintain regular contact with the UNI-SET project and share their approaches to implementing this Agenda. This will help other institutions learn from what does and does not work, and will also help compile the necessary evidence of successful implementation of this Action Agenda. As with all major social challenges, the energy transition is an opportunity for universities to maximise their traditionally competitive approach to enhance quality and excellence, by adding a new emphasis on cooperation within and between universities as well as with new entrants/partners. This will allow universities to mobilise their pivotal role in tackling the challenge of achieving a low carbon economy. However, universities will need to change to drive this transformation, so they are strongly encouraged to identify their position on the change path described, and to move swiftly to ensure the successful implementation of this Action Agenda, which will benefit the society at large.

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1. Energy Infrastructure - Smart Grids - Distribution Networks

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The functionality of grid components and distribution of grid dynamics	The interplay of distributed generation/local use/network operation constraints to ensure grid stability and energy efficiency	Propose solutions to update network operation to emerging constraints, with the ability to work across borders between different systems
	Individual/multi energy grid components and (multi-energy) system theories/interactions	Holistic system analysis and modelling of electrical grids, thermal and gas distribution systems as multi source/carrier systems	Overall energy system analyses and implementations to improve energy flexibility by playing on the different energy vectors
		Control and communication structures for smart grid systems, including big data elements	Integrate correlated information and synchronized measurements
Social	The role of consumers in demand and generation	The value of critical energy infrastructure for different consumer types	Create/propose new types of utility/prosumer contracts and interaction with existing regulatory environments
	The social impact of the various energy markets	Solutions for overcoming potential barriers	Problem-solving from the start to the end of a project
	User engagement with their energy consumption	How user involvement affects the energy system	Professional, social/environmental contextual awareness
Economical	The costs related to grid operation	Design and propose innovative tariff schemes to positively influence the energy market in certain directions	Propose solutions compatible with the local energy market and required future shifts
	Energy markets	How energy market participation might affect control	Optimise market participation for different actors
	Business cases for different actors	Business cases from a consumer, utility and/or aggregator point of view	Propose business models for complex energy systems
	kW vs kWh tariffs, capacity/consumption prices of smart meters	Business models for technologies serving different grids	
Political	The role of regulators and grid codes	Country differences in regulatory environments - identify/propose future improvements	Apply grid codes
	Legislation issues and potential multi-scale governance of energy systems	Potential legislation barriers for multi-energy systems and how to overcome them	Appreciate the importance of legislation and standardization
	The political agendas of actors along the energy value chain		Interact with different actors along the energy value chains

2. System Simulation / Modelling

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	Model systems in relevant simulation programs	Use of steady-state and transient (multi-physics) simulation software for residential/commercial buildings	Create models at various scales, validate them against real energy consumption data, critically evaluate results
	Principles of modelling and numerical simulation	System modelling tools, potential optimisations and limitations	Contribute to the design of (nearly) zero energy buildings, through appreciation of the challenges related to upscaling existing solutions
		The mathematical complexity required to model multiphysics systems and consequences for decision making	
Social	The influence of environment/occupants on energy generation/demand	Behavioural models of building occupants and their effect on internal gains/loads	Understand building energy balance from energy bills
	The application of principles of user interfaces	How limitations/restrictions and user interaction can be introduced to models	Contextual awareness
	Some of the potential barriers that affect simulation outcome (appreciate and possibly alleviate)	Algorithms for data aggregation for large sets of energy users in near to real time to improve decision making	Negotiate solutions based on scenarios and market models
Economical	Short and long term financial implications, e.g. payback time	Financial analysis/predictions based on different scenarios and investments	Perform economic analysis/prediction/modelling
	Energy market variations and their potential implications for system control	Pareto front theory to optimise the choice of energy conservation opportunities	Evaluate market influence on systems
	Economic scenario evaluation	Increasing the parameters included for scenario evaluation	Optimise systems with a large number of variables
	The impact of National Legislation on subsidies and incentives for technological developments/implementation	Sensitivity analysis to compare different scenarios and propose legislation/standardisation changes that will lead to improvements	Appreciate the effect of legislation and standardization
Political	Analyse how legislation issues might affect model set up	Numerical simulations for systems with heterogeneous components and different time/legislation horizons	Include different policy making scenarios in energy system models
		Potential legislation barriers for multi-energy systems	Background knowledge to influence politicians on legislation
		Identify potential legislation barriers for multi-energy systems	background knowledge to interfere with politicians about legislation

3. Conventional Technologies: Geo-based & Nuclear

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	Fossil fuel and nuclear technology and their respective efficiencies	Maintain and improve existing installations, including when they are supposed to be used beyond their initial life span	Understand maintenance requirements for these technologies
	Appreciate the flexibility and challenges with these technologies	The possibilities and limitations of new designs	Safe use and decommissioning of existing installations
		Safe decommissioning for installations that will no longer be used	
Social	Social perception of nuclear installations and waste	The social impact of replacing these technologies with e.g. solar/wind and ensuring their social acceptance	Provide clear information and improve social acceptance/understanding of technologies and their solutions
	Social perception of fossil fuels and their mining, including fraction technologies	Ability to evaluate the benefits and disadvantages of mining fossil fuels versus other alternatives	
Economical	Economic viability of keeping old installations running versus replacing them with new, renewable technologies	Economic impact analysis of early decommissioning and replacement versus keeping installations open for their full life time	Appreciation of the economic models used and how they can be changed/improved
	Economic model and dependency on fossil fuels	Different economic models not based on fossil fuels and their associated taxes	
Political	Political links with the fossil fuel industry and its lobbying influence	Political agenda setting to move away from 'old' technologies	Provide fact-based reasoning for why these technologies should be decommissioned as soon as possible

4. (Renewable) Technologies - Chemical

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The various bio-refinery systems	Regional context to adapt bio-refinery systems to spatial context	Integrate resource-technology-demand systems on a regional basis
	The properties and limitations of bio/renewable resources	The environmental/climate impact on bio-fuel production (e.g. crop production/residues)	Appreciate the principles of the circular economy by being able to connect biological/chemical 'residues' to generation
Social	The social impact of bio value-chains, e.g. eliminate impact on food production	Value chain (re)balancing to benefit all actors	Grasp and being able to apply the principles of the circular economy
	The role of the various actors in bio value-chains	Different opportunities for improving the circular economy within society	
Economical	Bio-resource markets	Possibilities for optimising resource use on a regional basis	Establish innovative business concepts for bio/renewable resource use
	The impacts of a purely economically driven bio-resources movement		
Political	Regional governance	Legislation proposals to improve the use of local resources	Interact with regional, national, global actors to optimise local resource use
	The interaction of regional, national and global governance regarding bio-resources		

5. (Renewable) Technologies / - Electrical / Thermal

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	All renewable technologies to produce electricity/heat from renewable sources and their respective efficiencies	The most suitable technology for a particular location and user profile, given short and long term requirements	Design detailed systems, including connection to the grid and storage facilities, where necessary/suitable
	The average/yearly electrical/heat demands of buildings and industries	Disaggregate electrical/heat demand from total energy use	Establish integrated conversion systems
	Multivalent energy conversion technologies (e.g. CHP)	Holistic electricity/heat/multi-type energy management	
Social	Potential social opposition to certain technologies e.g. wind turbines	How best to overcome social opposition	
	The relationship between demand and the potential to cover this using renewable sources	Value chain balanced benefits for all actors	
Economical	The specific running cost of major technologies in €/kW	How to perform a detailed cost benefit analysis for renewable installations	Design detailed systems, including costs and incentive schemes
	The concepts of 'Capacity Factor' or 'Equivalent Hours'		Calculate cash flow and net present value of investments
	Payback times for renewable investments		
Political	Applicable legal incentives	Environmental and related building legislation	

6. (Renewable) Technologies - Energy Conversions

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The fact that a system does not need to be balanced for one energy type, and that conversions can provide a great solution	Integrate energy conversion technologies in multivalent (e.g. electricity/heat/gas) demand systems	Establish integrated conversion systems
	Life cycle, efficiency of conversion technologies and energy cascades	Holistic electricity/heat/multi-type energy management evaluation	Establish control systems for multi energy systems with good hosting capacity
	The value of multivalent energy conversion technologies for specific situations (e.g. CHP)	How to design control systems that allow and support multi-type and valued systems with type conversions for optimised overall efficiency	Propose solutions to improve energy flexibility by playing on vectors
Social	The social challenges of integrating renewables and making them the preferred solution	Techno-anthropological studies, interaction with suppliers and customers on the integration of new installations	Know how to engage society, how people react to renewable integration and how to change this
	How to break the conceptual boundaries between energy types and know that one can be (more) easily converted into another	Environmental issues for the establishment/installation of renewables	Know about environmental issues and propose legislation changes to promote CO2 reduction targets
Economical	How renewables can influence energy markets, and how conversions can change that market	Detailed calculation of investment payback time including maintenance costs, etc. using future scenarios	Design detailed systems, including costs and incentives
	The challenges of investment and return on investment versus potential market influences/ uncertainties		Calculate cash flow and net present value of investments
Political	The legislative impact of a single energy market versus a split between the different energy types	Regional differences in regulatory environments and how and why those should change	Interact with relevant actors on each of the energy value chains
	The political agendas of actors in the energy value chain	Potential legislation barriers for multi-energy systems that rely heavily on efficient energy conversions	Understand the importance of legislation and standardisation

7. Energy Efficiency

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The factors that influence systemic energy efficiency, incl. integrating energy along life cycles and within the spatial/geographic context	The relationship between life cycle and energy efficiency	Propose energy efficiency measures at process level, potentially driven by data gathering
	Collected data analysis and appreciation of the power of such data, accepting its limitations	Simulation results and data gathered from measured consumption to improve energy efficiency	Propose energy cascades and efficiency improvements in whole life cycles
Social	The deployment barriers for efficiency improvements	Social barriers as part of a holistic analysis to improve implementation/integration	Consider social barriers
	The roles of actors in and impact on efficiency improvements	The impact of (new) technical processes in their spatial and social context	Interact with actors along the value chain/in the spatial context to improve systemic energy efficiency
Economical	Life cycle costs analysis of energy use with regards to generation efficiency	Calculate ROI for existing combined with new installations	Propose profitable and sustainable (costing) solutions
	The impact of pricing scheme trends (e.g. pricing based on kW instead of kWh) on management and new installations		Propose innovative business models for increased energy efficiency (uptake)
Political	Environmental regulations on efficiency and requirements	Adequate incentives for citizens and companies to move towards better energy efficiency	Operate in/create a legal framework
	Potential impact of economic incentives for energy efficiency improvements		

8. Energy System Control

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The complexities (time, location) and limitations of system control, e.g. BEMS	Design and improvements (forecasting) for existing BEMS	Implement an energy monitoring/action plan
	Instrumentation for system control and monitoring	Design new control systems for emerging multi-power systems (e.g. inertia-less, multi-energy vectors, including storage)	Calculate KPI for energy use based on monitoring
		Impact of control units in complex energy systems to identify optimisation potentials/limitations	Design and evaluate control systems to optimise energy generation/consumption
Social	User interface design that engages users and more automated designs (customisable smart home setup)	Energy consumption display and improved consumption behaviour	User awareness of energy flow/consumption
	Behavioural impact on energy system operation and control	Testing various control schemes in living labs and evaluating social benefits/acceptance	Conceive and sell new user-centric control schemes
Economical	Visualization of economic benefits for users	Use of price signals and other (real time) incentives in the control system	Compare different control strategies in terms of costs and benefits
	Optimization criteria and associated time horizons	Definition of economic KPI applicable to energy systems	Be able to evaluate market influence
	Price based control for active demand response		
Political	Importance of and challenges in standardization	The impact of new regulatory requirements on existing control schemes	Contribute to new regulations
	Regulatory environments influencing control/protection issues	Potential legislation barriers for control in multi-energy systems	Understanding and influencing legislation and standardization

9. Energy Storage Technologies

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	Different storage technologies and their respective pros and cons	The optimal energy storage solutions for a particular situation/ setting	Design and evaluation of energy storage systems
	The energy efficiency implications of storage, often due to potential energy conversions	The choice of energy conversion and/or storage	Use and integration of storage systems
	The importance of storage for time/space balancing	The technological challenges of integrating storage, the need for and design of new storage solutions	Propose a holistic and realistic view of (autonomous) energy systems: storage, energy networks, vector interconversion.
Social	Critical evaluation of storage system acceptance and potential barriers	Solutions that improve social welfare	Quantify the impact of storage-based solutions on community scales
	How integrating energy systems can improve social welfare	Synthesising solutions to integration barriers	
	Environmental risks of certain technologies, such as batteries	Quantification of self-resilience and other benefits for various stakeholders (including end-users)	
Economical	Cost benefit analysis of purchasing energy storage for e.g. domestic settings	Market influence analysis of battery storage	Knowledge of market relations
	Impact analysis of storage on the energy markets and trading	The various uses of storage facilities, including linking up local geographic areas to share resources	Propose economically relevant storage solutions
	Operation-related costs for each energy storage technology		Compare and optimize system operation by coordinate investments
Political	Incentives to promote energy storage integration at a smaller scale	Potential legislation barriers for storage systems and ways to overcome them	Operate in any political/standardised framework
	Standardisation requirements to allow energy storage system integration regardless of the manufacturer	Critical analysis of energy related standardisation, its limitations and potential	Find new roles for utilities in evolving, storage-integrating systems

10. Technology Integration / Security

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	Technical barriers to system integration	Systems to overcome technical barriers for system integration/ collaboration	Ensure secure system set-up
	The challenges of security versus user friendliness	Security first, while not compromising user-friendliness	Prevent failure and ensure reliability
	The importance of fault prevention for energy systems	Fault analysis and identification of means to overcome them (automatically) to ensure system reliability	
Social	The actors from industry and at the industry-society interface concerned with energy integration and security	Key stakeholders for energy integration in industry and between industry and society. Ability to analyse and influence them.	Guide participatory planning processes for energy integration in industry and across building walls
	Potential threats to energy stability due to the increased complexity of the socio-technical element of energy systems (more decentralised, more governing actors, prosumers)	Systems that are secure, but also user friendly	Inform society about how to handle energy system security
Economical	Economic pros and cons of (reliable, and non-hackable) security, e.g. brand reputation	The maintenance costs of ensuring secure systems, versus outage costs	Calculate business cases for secure communication systems
	Implications of breaching security and privacy	Cost implications of ensuring continuous compliance with legislation and standardisation	Be aware of risks versus costs
Political	Legal data handling requirements	The legal and standardisation requirements and needs to ensure better integration and security	Be aware of potential risks
	Customer rights and implications	Methods to ensure energy reliability is not a government, but energy supplier responsibility	Inform customers and industry of data security issues and how to overcome them

11. Technology “use” - Reliability / Maintenance

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The implications of the need for maintenance	Maintenance approaches for energy systems	Develop a maintenance/safety plan for an energy system
	How to achieve (long term) reliability	How to analyse and improve maintenance, based on past data to improve overall system life cycle	Design systems for reliability and easy maintenance
Social	Safety issues in maintaining energy systems	Socially acceptable maintenance plans that reduce overall impact while improving reliability	Understand the communication and employer implications of maintenance and achieving reliability
	Implications of essential repair work for communities	Consumer-technology interaction, identifying ways to improve this for existing/new developments	Appreciate how humans/technology interact and how this affects reliability/maintenance
Economical	Economic implications of poor maintenance/safety	The economic benefits of a good maintenance regime	Appreciate the relationship between economics, reliability and maintenance
	Economic implications of maintenance versus replacement with e.g. new, more efficient solutions	Economic analysis of ‘cheap and cheerful’ versus quality products for reliability and maintenance	
	Economic implications of the need for maintenance		
Political	Legal safety and environmental impact requirements	The political impact of poor reliability/maintenance on communities	Understand the political implications of poor maintenance resulting in poor reliability
		Legal responsibility for maintenance and reliability	

12. Data Analytics

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	Methods of data analysis	The intricacies of data analysis and an ability to apply them	Use monitoring systems to check energy system KPI
	The challenges/limitations of data collection, analysis and prediction	The pros and cons of time granularity in information gathering and its impact on e.g. demand response	
Social	The implications of data gathering on social/consumer behaviour	Role-based access to energy information	Be able to derive and correlate information from various sources in energy systems (real-time, statics, online)
Economical	The costs associated with each phase of data acquisition, communication, memory	Costs components of big-data analytics for energy systems and potential impact/benefits	Design and maintain operation of cost-effective ICT systems
Political	The principles of data protection, integrity and privacy	Coordinating privacy requirements with control needs in critical energy infrastructures	Correlate energy regulations, ICT standardisation and security-enabling policies
		The implications of unauthorized access to critical data	

13. Transport - Personal, Public and Goods

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The importance of a good transport system for transport energy requirements	New transport models using different energy types	Link transport needs with energy requirements
	The impacts of new mobility models on energy demand	Improved, more flexible transport infrastructure, vehicle and service design	Design/propose improvements to transport system infrastructure and/or vehicles and/or services
	Transport network infrastructure challenges and the developments/maintenance required	Methods to improve efficient road use (e.g. autonomous driving)	
Social	The barriers to faster e-mobility. Better distribution strategies	Human transport needs to create better public transport facilities that align with transport requirements	Understand the human factor in transport and its impact on perception of freedom of movement
	The barriers to public transport versus 'overload' in certain environments	The acceptability of various models of autonomous driving	
	Public barriers to e.g. autonomous driving		
Economical	The economic impact of traffic jams	Suitable solutions to traffic jams -their economic investment requirements versus benefits	Identify the economic impact of e.g. traffic jams, changes to transport tax schemes and public transport costs
	Tax/costs of public or private transport		
Political	Political influence on the development of public transport versus 'support' for personal and freight transport	Models that investigate improvements to public (freight) transport facilities and their economic impact	Appreciate and improve the political framework for transport to ensure better acceptability and use of available infrastructure
		Political framework development for e.g. autonomous driving vehicles	

14. Urban Planning

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	Regional energy systems and their demands/generation	State-of-the art systems for industrial/urban settings including resource/regional systems	Generate optimal resource-technology demand systems
	Urban/community energy systems	National energy modelling with the potential to interact across any boundaries	Develop a comprehensive territorial energy model
			Propose urban planning improvements for energy efficiency
Social	Environmental impact of energy infrastructure	Energy infrastructures and 'Not in my backyard' syndrome	Lead public debate on energy planning decisions
	Interaction between urban centres and hinterland		
	Impact of spatial distribution of demand and resources		
Economical	Economic benefits of improving urban planning for energy requirements	Resource-technology-demand system analysis to identify opportunities for innovative business models	Economic appreciation of mutual interaction with urban planning
		Economic aspects of urban scale energy planning	
Political	Implications of existing agendas of actors in urban and spatial planning	Planning and setting/steering urban design standards	Lead political debate about the pros and cons of certain urban planning decisions and their energy impact

15. Building Design

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	Thermal properties of materials and building components	The optimal building envelope solution for a given building and climate	Support architect - engineer interaction to ensure energy efficient building design
	Mass/energy balance of buildings	The optimal technical systems for a given building typology	
	Impact of architectural design choices on energy (e.g. orientation of the building/rooms)	Integration of renewables in (new and renovated) buildings and technical systems	
Social	Environmental impact of building materials/approaches	Marketing aspects of energy efficient building design	Promote sustainable building design
	Social acceptance of sustainable building materials	The impact of fully sustainable building design	
		An understanding of construction time frames and the need to exceed current standards	
Economical	Cost of main technologies (thermal insulation, high efficiency windows, etc.)	Energy/cost analysis of different building and technical system solutions	Economic benefits and impact of using sustainable building materials
	Impact of economy on building design decisions	New models that ensure the use of sustainable building materials instead of environmentally harmful ones	
Political	New building legislation/requirements	How to implement and propose improvements to regulations and standards for energy in buildings	Propose improved legislation that enforces more sustainable building design
	EU/national directives for zero carbon building design		

16. Energy Communities - Society

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The technical challenges of building energy communities	Energy system solutions compatible with community needs	Examine/improve end-user practices
	The challenges and need for distributed generation	How to ensure that distributed generation does not affect supply reliability	
Social	Drivers for socio-cultural acceptability	The effects of distributed generation	Participate in the modern energy industry
	The changing roles of energy communities	Dissemination strategies for renewable energy technology	Communicate effectively with a variety of end users
	The need for building communities	Potential renewable energy technologies for future application and how users and producers respond	Work with different stakeholders
Economical	Differences in energy consciousness of both energy producers and consumers	Energy production and cost case studies to explain the historic and contemporary needs and uses of a specific energy technology	Awareness of significant historic developments for energy initiatives
	The history of energy production and costs	New economic models that support community responsibility for energy generation	Be an effective energy market operator
Political	Political framework requirements to support communities at global, national and regional levels	Improved governmental structures for larger community development/support	Support the 'return to the community'
	Supporting means for a cultural shift to community development	The need for a shift towards communities	

17. Energy Market / Economic Model(s)

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The Energy Service Company model	European Payment Council schemes	Energy and emissions trading
	Operators, players and mechanisms for influencing the energy market (economically and technically) - control	Primary, secondary and tertiary control at Transmission System Operator (TSO) level and price related control in smart grids	Understand user and actor influences on the energy market
	Development of transmission and generation in energy markets, e.g. based on system limitations	How different actors can influence the control and setting point for loads and generation	Understand how the market affects energy system control
Social	How to engage private consumers in smart grids	Techno-anthropological surveys	Understand user involvement
	The social impact of changing the energy market model to e.g. prosumers	Energy market models that benefit prosumers and service companies	
Economical	Economic incentives for energy efficiency and renewable energy systems	How you can earn money on the market, and the impact of investments and operating costs on decisions	Know about market structures and how to bid on the market
	How to participate in the key financial instruments of the energy market	Forecast analysis, risk analysis, how to act on the market	Make reasonable forecasts for how to act on the market
	Different market types: day ahead, balancing, spinning reserve etc.	How financial instruments can be used to manage risk	
Political	Legislation on market interaction	The Nordic, European market	Know about market structures and how to bid
	How legislation influences markets in a multi-energy systems setting (or how these systems are disconnected)	How different market structures relate to different energy sectors	How the market will influence smart grid systems

18. User Behaviour/ Engagement

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	Techno-anthropological surveys and questionnaires	Statistical analysis of results, definition of uncertainty	Communicate with customers
	Technical implications of a move towards decentralised/prosumer based generation	Design control systems that operate locally, but can also interact with more centrally controlled operation	Understand why and how various groups of customers/citizens have various needs and different abilities to engage and benefit from various technologies
Social	How discourses, institutions and professions have historically shaped the conceptual landscape of robust and socially responsible technological innovation	The methods, tools and skills appropriate for studying consumer practices	Highlight different consumer practices
	Energy consumer practices and the willingness of consumers to change energy behaviour	Cases of robust and socially responsible energy technology innovation	Identify opportunities for the development of robust and socially responsible energy technology solutions
Economical	Inform consumers of good practices to supply their own energy demand	The potential benefits of incentives and whether this aligns with the best energy provision system for this consumer/prosumer	Economic benefit for users
	Cost benefit analysis for private prosumers		Communicate with customers
Political	Knowledge of incentives and legal framework for prosumers (e.g. interconnection to grid)	Legislation improvements that support prosumer behaviour	Good background for discussing user involvement
	The mechanisms of how political decisions (on regulation, energy or CO2 taxation, incentives) influence end-user energy consumption	The potential impact of legislation decisions on user behaviour and technology/economy/etc.	

19. Professional Behaviour “of the future” / Ethics

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The importance of holistic and detailed points of view	Detailed design/analysis without losing the larger/holistic view that links relevant social/economic/political aspects	Combined technical and business mind-set
	The need for multi-disciplinary developments/teams/etc.	Entrepreneurial spirit to drive technical progress in leaps rather than incremental steps	Entrepreneurial drive to deliver the best possible product within the available time frame
	The ethics of technology integration, such as big data gathering.		
Social	Social enterprise and its importance for energy and in general	Interpersonal skills that allow communication across discipline boundaries	Teamwork skills and ability to communicate with different types of people (customers, colleagues with different backgrounds)
	The social impact of technology products	How society can move from individualism towards communities	Leadership to move the world/society on to a better future
	Communication with different social strata		
Economical	How to change from an economically driven market to a socially driven market	Ability to deal with the challenge of time/deadlines versus the economic costs of failing to deliver a quality product within a timeframe	Deadline driven and well organised to achieve set goals
	The economic impact of getting it wrong and needing to redo the work, versus getting it right first time	Evaluate short and long term economic plans and potential impact factors	Manage innovation at the 'right' pace for product development
	Short and long term organisational/development planning		
Political	The need to overcome boundaries between disciplines	Solutions that break down barriers between disciplines and support truly interdisciplinary development	Multi-disciplinary, appreciates the interconnectedness of everything around us, and of ourselves
	Political influence and leadership supporting social enterprise versus profit-driven business	Socially driven enterprise models and how they can make the world a more community driven environment	
	The consequences and responsibilities of power and decision making	Evaluate decisions and their short and long-term impact	

20. Future developments

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The time frame of technology design and use	Design technologies that will be compatible with the technologies of the future	Customer/future focused design
	The impact of flexible technology design	Customer centric design	
		Technologies beyond current thinking/incremental change	
Social	Selected, cutting-edge and emerging energy technology innovations	How cutting-edge energy tech science suggests new kinds of behaviours, including those not previously imagined	Identify and promote energy technology innovations for sustainable transitions
	The fact that change is an essential part of life, to be embraced	Consumer interaction to better understand their needs for new developments	
Economical	The applicability and application of the circular economy model	Economic justification of investment to develop revolutionary technologies	Understand economic models and their impact on future developments
		The social enterprise models applicable to the energy sector	
Political	Regulations and incentives in the field of energy, and any incompatibilities and trade-offs	How to steer future legislation	Develop future-proof legislation
	The trade-off between legislation and flexibility	Ensuring application flexibility and avoiding abuse of legislation	

21. Policy / Standardisation

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The impact of policies/ standardisation on technical developments	Design systems that comply with policies/standards	Independently analyse the impact of policies on technology
		The development of new standards	Provide technical/scientific guidance for policy development
Social	The social acceptance/impact of policies	How to communicate policies effectively to those affected	Communicate complicated policies to consumers
	The social impact of standardisation	The social impact of standardisation and changing standards	
Economical	The economic implications of policies/standards	The impact of individual policy instruments on financial decisions (e.g. on sustainable energy and energy savings)	Independent advice/development of legislation/standards
	The main drivers for legislation and standardisation (other than the economy)	The best scenarios for standardisation	
Political	The impact of policies on sustainable development	The restrictions of policies/ standardisation and the flexibility required for future developments	Independently analyse the impact of various policies.
	The political framework and potential friction between the different areas within this framework	Political framework analysis to allow simplification for 'users'	

22. Related society

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	Opportunities for technology to help humanity, i.e. identify gaps in the market	Products that fill gaps in the market and aid humanity and the challenges we face	Social awareness when developing new products
	The challenges of different demographics and how they interact with technology	The best approaches to designing products that target as wide an age range as possible	
Social	The impact of demographic change on energy demand (not only with regard to population but also with respect to lifestyles etc.)	The potential changes required in energy supply (systems) regarding demographic changes	Social behaviour and its relationship to e.g. health, education, etc.
	The relationship between health and social behaviour	Better educational models that deliver the right skill set, more than just knowledge	Constant professional development to support yourself instead of being a burden
	The importance and limitations of education		
Economical	The economic impact/differences for different demographic groups	Modelling how changes to healthcare can improve lives and reduce economic impact, while developing transition plans to get there	The importance of economics and its relationship with implementation/change timescales
	The cost of getting healthcare wrong or failing to work preventatively	The impact of education on a country's economic development	Identify valid short/long term economic investments
	The economic benefits of collectively investing in education		
Political	The relationship between politics and demographic groups	Political models that support all demographic groups at an appropriate level	Understand the different political challenges faced by different demographic groups
	The impact of 'one-size-fits-all' solutions on the different people this aims to support	Political models that do not apply a 'one-size-fits-all-model' to only support people where necessary	Understand policy flexibility and potential restrictions
	Policy needs and restrictions in education		

23. Related environmental

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	The relationship between technology and the environment - constructive and destructive	The relationship between technology and the environment and how it can be improved	Design new technologies that have lower/no environmental impact and support the environment
	The environmental impact of using specific materials, e.g. precious minerals	Technology design to aid the environment by taking some basic principles, e.g. circular economy, into account	
Social	The social importance of the environment (food, water, agriculture, etc.)	Methods to improve the understanding/acceptance of living with as opposed to living off the planet	Socially and environmentally aware
	Society's acceptance of the importance of our environment/planet	Analyse models for the change towards a 'give and take' principle versus a 'take only' approach	
Economical	The economic costs/benefits of getting technology right for the environment	Economic environmental costs	Know that economics is a human construct and that the environment is often 'a given'
Political	Political responsibilities to improve/respect the environment when designing technology	Political responsibility and demands on legislation to ensure respect for the environment	Possess political awareness of legislation and its environmental impact
	Community impact on the development and need for political legislation to support the environment		

24. Related industrial

Topics (for courses)	Understanding, Background Knowledge, Comprehension, General Appreciation of ...	Design and Implementation / Deeper (Master level) Appreciation of ...	Employment Skills
Technical	Manufacturing processes and issues	The implementation of waste recovery technologies	Propose solutions for recycling waste
	The impact of wasteful production processes	Minimising manufacturing waste from the design process onwards	Improve product design to minimise waste
	Waste treatment challenges	Design taking many requirements (economic, waste, social, etc.) into account from the start	
Social	The impact of product manufacturing and social acceptance	New products that are socially accepted and have lower environmental impact	Consider social limitations
	Socially acceptable marketing	Marketing the social value of products	Socially acceptable product design and marketing
	Social conflict between perceived and real product value		
Economical	Economic models for manufacturing	Innovative economic models for waste management and recycling	Make recycling profitable
	The economic effectiveness of resolving problems at each design stage	The economic value of waste in a circular economy	Develop circular economy opportunities
	The economic cost of waste		
Political	The legal and political framework for waste management	Adapting legal and governance frameworks to the circular economy	Promote the circular economy
	The impact of the legal framework on sustainable, socially responsible manufacturing	Developing a legal framework to inform people of the social/ environmental impact of products	

Appendix B - Case Studies

Energy Efficiency

Example 1 - Energy Efficient Regional Resource Use

Optimal use of existing, preferably local, resources is the ultimate improved efficiency goal. This requires students to generate holistic resource systems that make optimal use of restricted resources with state-of-the-art planning methods (e.g. Pinch, Exergy Analysis or Process Network Synthesis). When a group of (ideally engineering and urban/spatial planning) students is familiar with these technologies, they can be asked to optimise the resource use of a given region/urban settlement. Whenever possible, representatives from the region should be involved. The students will need to see data about the potential energy sources (bio, wind, hydro, solar) in the region, about demand (energy, subsistence, buildings), demographic development, existing businesses and existing infrastructure.

Each group of 4-5 students plans a method to overcome the existing problem. They propose an optimal resource-technology-demand system, integrating existing sites and infrastructure, and identify the most beneficial investments available. They present their results to the whole group, including tutors and regional representatives, followed by a discussion to analyse the strengths and weaknesses of the different approaches.

Example 2 - Multi Criteria System Optimization

A big chemistry plant produces a given number of tons of waste hydrogen and a given quantity of waste heat at 250°C per year. Students are given the annual electricity and primary energy resource consumption of the plant. CO₂ emissions for chemical and own energy production are also provided. An onsite captive fleet is attached to the plant. Energy networks (electricity, gas and potentially heat) are part of the boundary conditions. The plant is located in a mid-rural territory that produces agricultural waste (wood, straw and manure are available). The region is rather windy, so a field of wind-turbines is currently being explored, while the yearly wind profile and installed power capacity are also provided.

Students are asked to:

- 1) Exploit waste as a resource
- 2) Create synergies within, and where possible across, plant boundaries
- 3) Increase the use of decarbonized resources.

Their main goal is to achieve multi-criteria system optimisation.

Groups of 4-5 students research the problem from a variety of perspectives, e.g. CO₂ budget, deep decarbonization potential, economic impact/potential, energy efficiency, etc. An initial brainstorming is held to define potential technologies and synergies beyond the plant boundaries. Each group performs part of the modelling and simulation of the various potential technologies and synergies across plant boundaries. Results are discussed in a consensus meeting and presented to a broader panel of experts including people with non-technological backgrounds (geography, psychology, social, regulation, governance).

Example 3 - Energy Efficiency Planning Methods

Implementing energy efficiency in industry often requires an innovative view of existing systems, which is a suitable challenge for creative young minds. Student Camps attended by students from different disciplinary background could be implemented.

A Student Camp should convene 20-25 students from e.g. engineering (industrial, chemical, energy), business administration and spatial/urban planning backgrounds, preferably from different universities and of different nationalities. Participants are then grouped into interdisciplinary teams of 4-5 people. As Student Camps are organised in cooperation with an industrial company, the groups are asked to improve the overall energy efficiency of e.g. a site or building, using their creativity and building on their planning skills and knowledge.

Members of the company management outline the current situation and company plans. Students then design measures to increase energy efficiency on-site, taking advantage of potential energy cascades. They propose innovative business approaches and models to achieve energy efficiency targets. Students are supported by academic instructors from various universities as they work.

Smart Grids and Energy Systems

Example 1 - Energy System Integration

Multi-energy systems integrate different energy vectors to achieve better energy use, reducing CO2 emissions, and achieving major economic savings. This requires a focus on the technical, social and human aspects of i.e. a smart grid or smart city case studies, preferably involving students from several different areas/backgrounds such as: techno-anthropology, economics, energy planning, electrical engineering, thermal engineering, control systems, communication and big data studies.

Groups are asked to select a real-life scenario in which electrical, thermal and/or transport issues need to be solved. They have to use knowledge from their various academic backgrounds to find a common solution, addressing the technical, economic and human sides to their chosen scenario.

All students work on the same context, but the focus of each project is different, according to the backgrounds of the students involved. Electrical power engineering students focus on the electrical grid and should be able to simulate and verify their project using the real data provided/obtained. They should also demonstrate awareness of how control, communication, thermal and/or transport systems interact with economics and human behavior, based on input from the other students. Economics students are to focus on energy market issues and describe the business cases, but should also have a general idea of technical system setup and control requirements.

Example 2 - Energy Storage

Energy storage is expected to be widely used in different ways in the future energy system. This could involve electrical battery storage, thermal storage or gases like hydrogen made from excess electrical power produced by wind turbines or PV systems.

Students therefore need to know about the different storage technology types and their applications in different contexts. For example, electrical battery systems can provide ancillary services and/or voltage control and can also be used to combine electrical and thermal systems using electric boilers or heat pumps to heat water for thermal storage. They will also need to appreciate demand management using e.g. electric vehicles in vehicle to grid or grid to vehicle conditions etc.

These topics could be taught as elective courses including workshops on the different technologies and storage applications for the respective energy vector markets (electric, thermal and/or gas) with their respective time scales. Workshops should also include the essential elements of energy storage business cases and legislation. Students must be able to scale, model, analyse and control the storage systems, and understand how they can be used for interactions between different energy vectors and seen in relation to a whole energy system and the relevant energy markets.

Example 3 - Scenarios for Problem Based Research

In identifying suitable scenarios for problem based research, students must learn to appreciate how to use selected methods and theories to examine technical-scientific areas and how these influence and are influenced by human behaviour. This can be achieved by asking students to study human energy behaviour in the transition from consumer controlled energy production to production controlled energy consumption for residential, transport and workplace use.

If a stronger focus on consumer practices and opinions is required, students can be asked to distinguish between mental and physical barriers when rolling-out land-based wind turbines, and how realities compare with public opinions.

A good understanding of the drivers of socio-cultural acceptability is currently key to technology integration, and would provide a good understanding of the energy consumption reductions achievable through changes in some of our energy consuming habits, and of what it will take to make us change our habits, if this is possible.

Renewables Integration

Example 1 - Data Collection and Processing

A knowledge of actual energy consumption is a necessary, preliminary step for developing any action plan for energy integration. This concept applies equally to industrial, tertiary and residential end users.

The course covers a wide spectrum of skills as it addresses: the technical characteristics of instrumentation, sensors, data acquisition systems, BEMS, measurement methods, statistical processing of experimental data, definition and calculation of KPIs, the impact of occupant behaviour on energy demand, and more.

While some teaching provides the information necessary through traditional lectures, once basic knowledge has been acquired, students work in groups of 3-4 on case studies such as:

- 1) An industrial monitoring system to log the energy consumption data of (individual) production processes
- 2) A tertiary building equipped with a BEMS designed to collect environmental parameter data (outdoor/indoor climate, IAQ, etc.), as well as information about occupancy, lighting and HVAC,
- 3) A large residential complex connected to a central heating plant (e.g. district heating), in which individual household thermal energy consumption for heating and DHW production is measured.

KPIs are identified and compared against suitable benchmarks for each case. Energy saving measures are proposed to achieve the KPIs, and the potential for low-cost (or zero-cost) measures at system O&M level is highlighted.

Example 2 – Energy Integration, a Holistic Perspective

Energy integration can often be improved by looking beyond individual systems and across the boundaries of a system. It is therefore important to learn to examine system-of-systems. This assignment is based on students identifying suitable efficiency improvements in a real-life situation provided with enough technical information (equipment data sheets) and information about the legal framework and user expectations (e.g. a hospital). Students are then asked to work in small groups of 3-5 to identify suitable improvements and potential implementation barriers. They are given a restricted budget to implement their improvements. Each group competes to achieve the best overall improvement, and at the end of 6 weeks, they all have to explain how they went about the exercise, which solution they came up with and how effectively they think it would be integrated in real life. Assessment is performed by their peers using 5 agreed criteria. Each criterion has a set number of marks to be shared among their competitors. The presentations also open discussions about the different routes suitable, their pros and cons. A few devil's advocates are brought in from a variety of disciplines (social, political, technical, economic) to improve the depth of these discussions.

Example 3 - Renewable Energy Resources

Renewable energy resources are diverse and exhibit different characteristics that affect the way in which they can be used. This course aims to provide master's students with a good understanding of the various renewable energy resources, their implications for the energy system in general, and for specific projects. For example, students must understand the spatial and temporal variability of solar power/radiation at different scales to design any solar energy plan or project. The course covers policy definition, the early stages of feasibility analysis all the way to the actual design and operation of the system. We will also explore how certain renewable energy resources show a degree of correlation at specific spatial and/or temporal scales that should be exploited to optimise the integration and operation of these resources in any given energy system.

The course uses project-based methodology, with students working in small groups of 3-5. Each group performs a feasibility analysis (covering technological and non-technological aspects) for a renewable energy project in a certain region, starting by assessing the most relevant renewable energy resource to use. Each group presents their progress to the class at every major milestone, opening up a discussion moderated by the professor. Assessment is based on these class presentations and the final project report prepared by each group.

Appendix C - SHAPE Energy Project

The SHAPE ENERGY project identified 20 key energy-related keywords using the expertise of an interdisciplinary group of leading European energy scholars²⁶.

The SHAPE ENERGY keywords are a useful benchmark for important energy topics identified by social scientists that could be used for teaching straddling different disciplinary communities. The Shape Energy Annotated Bibliography is another valuable resource.

The EUR 2 million EU Horizon 2020 SHAPE ENERGY (Social Sciences and Humanities for Advancing Policy in European ENERGY) project aims to review and produce state-of-the-art energy-related Social Sciences and Humanities (energy-SSH) research, in addition to gauging what non-academic stakeholder communities want from energy-SSH. Its core purpose is to use that as a basis for providing recommendations to the European Commission on the future of energy-SSH in EU energy policymaking, including funding research and innovation. SHAPE-ENERGY runs for 2 years (from 1 February 2017), and is co-ordinated by the Global Sustainability Institute, Anglia Ruskin University (Cambridge, UK). More information can be found at: www.shapeenergy.eu

SHAPE ENERGY runs a range of activities including (but not limited to): 18 multi-stakeholder workshops in partnership with cities across Europe, MEP workshops in Brussels, conferences, Horizon 2020 sandpits, early career researcher summer schools and secondments to Horizon 2020 energy projects, funding for collaborative think pieces, funding for an innovative 'research design challenge', and online policymaker-citizen debates. The project has also published numerous energy-SSH resources that may prove useful as teaching aids, such as: annotated bibliographies on energy efficiency and using less, competitive, secure, low-carbon energy supply, energy system optimisation and smart technologies, and transport sector decarbonisation, theme reports on multi-stakeholder interests, gender, energy justice, the active consumer, and a reflection on the 200+ responses from the energy-SSH community to a call for evidence.

Further to the themes highlighted within these resources, the SHAPE ENERGY project also produced a SHAPE ENERGY Lexicon using the expertise of an interdisciplinary group of leading European energy scholars. This lexicon includes a 20-minute exercise for readers (and educators) to follow, in addition to presenting the various cross-disciplinary definitions for 20 keywords – all of which were deemed crucial terms in the interdisciplinary study of energy. These keywords are:

- Energy behaviour
- Energy citizen(ship)
- Energy consumer
- Energy culture(s)
- Energy efficiency
- Energy future(s)
- Energy governance
- Energy justice
- Energy models
- Energy policy
- Energy poverty
- Energy practice(s)
- Energy security
- Energy social science
- Energy storage
- Energy transition
- Engagement
- Low-carbon energy
- Smart
- Sociotechnical

Appendix D - Recommendations from UNI-SET Energy Clustering Events

Appendix D includes some of the main messages that emerged during the UNI-SET Energy Clustering Events. Chairs and rapporteurs of several parallel sessions used a common template to gather the main discussion points. The full reports can be consulted on the UNI-SET event website²⁷.

The messages in this Appendix are categorised into: General recommendations (D1), Energy efficiency recommendations (D2), Smart grids and energy systems recommendations (D3) and Renewables integration recommendations (D4). Each section includes messages in 3 main areas: Education, Research and Innovation, Social Cooperation and Outreach, and Messages for Policymakers. These are in line with the main action themes in the Roadmap for European Universities in Energy.

D1. GENERAL RECOMMENDATIONS

D1.1. Education, Research and Innovation

- Social sciences and humanities should be integrated with technological sciences to solve complex problems
- University leadership should support multidisciplinary activity
- Increase funding for master's/research projects in new areas
- Multidisciplinary research: potential publication in lower-impact journals
- Integrate state-of-the-art energy research into educational programmes by:
 - Master's theses
 - Facilitating invitations for students to attend outstanding research facilities
 - Remote access to labs and unique research facilities
 - Adapt teaching methodologies for future energy professionals integrating:
 - Project-based courses with an integrated approach, including team work (groups of 3-10 students), visits, and work with companies or municipalities on real world projects
 - Integration of innovation and entrepreneurship
 - Skills versus knowledge orientation
 - Alternative training, with students spending 50% of their time in industry
 - MOOCs (without ECTS) for students and citizens
- Basic and applied research should not be understood as a dichotomy – solving application problems often requires an understanding of and solutions using the fundamentals. It's an iterative process.
- Use online labs for distance learning. Involve students/campus living labs. Communication and cooperation between students and university leadership
- Create structures like Social Science labs for sustainable energy connecting people and ICT tools
- University organisation: establish profiling thresholds (e.g. expected % of social scientists, engineers etc.) when designing multidisciplinary courses
- Universities should support social transformation: co-construction, co-working: industry, government, civil society, campus facilities and human capital to be used for living labs (multi/interdisciplinary/holistic approach), greater freedom to implement the emergence of green teams (managing energy, waste, urban concern and communication, beyond energy and towards sustainability, provide a front desk for energy
- Bottom-up approach should be supported by university management. It takes time to work together (ca. 4 years), and needs: trust, dedication, money and flexibility
- Address Intellectual Propriety Rights (IPRs)
- Next-generation students have different learning needs and relational behaviour. Now more content is available online there is an increasing need for guidance and mentoring from teachers rather than content provision. New generations learn more in groups and are highly collaborative.
- Develop innovative educational modules for different student types: from online educational modules for next generation students, to more professional education for current industry/company managers (i.e. Energy business MBAs). Evolution of current education to more problem-based courses in Energy engineering
- Set demonstration off-campus
- Connect to existing repositories
- Cross border projects require the involvement of experts from different disciplines
- Develop tools such as the Decision Support System
- Address energy and climate together (energy transition)
- Implement a transversal approach for future energy education: make it theme-based (energy, maths and social sciences) and focused on actors (industry, government, research institutes, financial sector)

- Develop new Energy, Environment and Society master's programmes
- Develop practices to engage citizens: weekly informal lunches (open to all, free of charge), newsletters, living labs, workshops, representation at municipal and other forums, social debates
- University-based research to integrate more strongly with market needs
- National Rectors Conferences should consider promoting the development of joint Energy Transition master's programmes at universities in their countries
- Universities need to strengthen their post-doc capacities in this field to achieve the future breakthroughs needed in basic research

D1.2. Social Cooperation and Outreach

- Cooperate with industry at several levels: research projects, educational conferences and placements, advisory boards
- Learn from others – how could a culture of more industry funding/cooperation for low-TRL research be fostered in Europe?
- Public administration should be involved at different levels, i.e. local, regional, national, European
- It is important to establish networks and engage. Connect university authority with local institutions
- Innovation-stage R&D should create impact for university research
- Universities should be involved in providing scientifically objective advice, and need to develop researcher and staff policy literacy
- Develop multilevel collaboration between universities and local administration, regulatory state authorities and international experts, to achieve highly efficient processes for solving energy-related social problems
- Universities should be more courageous in establishing multidisciplinary courses. Resources are limited so a decision on where to focus them is needed
- Education should help understand consumer and citizen behaviour
- Teach communication skills to make it easier to understand the benefits of technologies
- Build on existing industry-university initiatives: visits to companies, student internships, teachers provided by industry working with academic teachers, doctoral students working on company projects, prize jury participation, etc.
- Participate in a coordinated manner in public consultations on energy priorities at both national and European level
- Involve students in research and curriculum discussions – they are the initial broadcasters
- Establish long-term partnerships to create win-win situations
- Accept the limits of human communication: information is interpreted by all actors

D1.3. Messages for Politicians

- The role of universities:
- Transfer knowledge
- Advise governments on energy policy
- Would an energy-quality label help?
- Strengthen awareness at primary/secondary schools
- Make more use of university potential (infrastructures, people, ideas, behavioural observation from living labs)
- Implement a favourable framework (legal measures) to foster industry investment in low TRL/interdisciplinary projects and initiatives
- Set ambitious technical and social targets (e.g. United Nations Sustainable Development Goals and University of Bergen strategy)
- Address the challenge IoT, the 4th Industrial Revolution is moving faster than the energy transition
- Research Councils and the European Commission should fund new innovations establishing University cooperations through research centres (real and virtual) that tackle energy transition challenges through education and research programmes

D2 ENERGY EFFICIENCY RECOMMENDATIONS

D2.1. Education, Research and Innovation

- Design open source tools for energy consumption analysis
- Reduce energy consumption in houses
- Convince stakeholders to invest in new concepts
- Remove non-technical barriers
- Make building energy reports easy
- Include social aspects and architecture in engineering, e.g. Techno-anthropology
- Link energy use with comfort and design
- Monitor education indicators: define Key Performance Indicators (KPIs) for management systems to ensure sustainable development and energy efficiency
- University leadership should take ownership of campus energy sustainability

- Develop guidelines to assess campus energy sustainability (and rank them)
- Develop campus energy manager profiles
- Complement research on new buildings by retrofitting existing constructions
- Technologies and services have to be conceived in an integrated manner to provide added value - integration and a systemic approach is key
- Place importance on business models

D2.2. Social Cooperation and Outreach

- Address the lack of two-way communications between resident comfort and the energy manager
- Address the gap between managers' and users' knowledge and power (users may refuse to be involved, allowing this discrepancy)
- Use smart ICT to collect data and share information with energy managers, technology providers, public administrations
- Obtain feedback and gamify energy use to achieve wider participation
- Develop an interactive social network with mobile apps
- Make people bottom-up monitoring devices using ICT
- Various, flexible partnerships to improve energy efficiency should be an opportunity for universities to engage society using research and education
- Mix energy efficiency, renewable energy sources and Demand Side Management (DSM). Decrease energy demand using energy efficient measures, then use renewables

D2.3. Messages for Politicians

- Develop policies and legislation while technologies are still at lower TRLs to achieve faster deployment when they are ready
- Promote good regulatory measures
- Promote pragmatic approaches, e.g. Energy Efficiency Directive: energy service costs should be based on consumption. Heat metering is causing trouble at various levels

D3 SMART GRIDS AND SYSTEMS RECOMMENDATIONS

D3.1. Education, Research and Innovation

- Test systems with different energy carriers (natural gas, oil, hot water, steam, etc.)
- Emerging synchronised measurements can contribute to more accurate monitoring and control, even extending from wide areas to local distribution systems
- There is a need for training on effectively communicating smart meters and energy use to end-users
- The new field of education has to exceed standard dissemination
- Establish new master's programmes on how to communicate emerging technologies like smart metering, which may have a strong impact on the overall energy system, to end users
- Research the impact of different interfaces to inform different types of consumers
- Pay attention to the scale of the system addressed and whether energy systems can be analysed bottom up/top down
- Train system experts
- Good examples of cross-disciplinary challenges include: energy storage, efficiency and management, spatial, urban and solar application
- Energy storage technologies and grid management should always be very innovative and multi-disciplinary due to their future-oriented, social perspectives
- Provide hands-on interdisciplinary options to impart skills for building and component design (e.g. planning, measurement, app development)
- Connect with smart city research: scale-up from campus to city

D3.2. Social Cooperation and Outreach

- Address the lack of standardization in communication protocols and informative user feedback. Work out how to include users in the control loop, how to share information benefits
- Empower consumers (contracts, real-time prices, tariffs etc.)
- No 'one-size-fits-all' solutions (e.g. consider age when receiving and using information)
- Redesign roles: how do companies communicate with customers (e.g. smart meters)
- Use metering as an opportunity for companies (DSO) to improve the quality of their own data – which can lead to significant decreases in operational expenses
- Use agent based-modelling/game based modelling for optimised demand strategies

- Achieve results through cooperations between industrial and academic project partners, including external/local stakeholders (e.g. city mayors), representing different approaches and expectations
- Adapt passive housing to domestic markets and achieve knowledge transfer
- Foster interoperability, work with open API, open data, etc.
- Strengthen local, regional and national professional networking initiatives, e.g. clusters of companies and universities

D3.3. Messages for Politicians

- Third generation smart metering needs better customisation for different uses and to be open to evolution and upgrading
- Industrial funded research can lack independence
- Keep the focus on all forms of energy rather than just electricity
- Greater energy savings and flexibility are achieved when viewing the whole energy system
- Reliability of supply must be guaranteed
- Existing and future storage technologies need to be integrated with national regulations and grid restrictions
- Coordinate input to legislation/policy frameworks
- Provide education/information for government
- In the era of Big Data, the data is owned at national level. Achieving better solutions at European level and cooperating in networks remains a challenge
- Incentives are important for investment in innovative technologies: at customer and global economy level. Regulatory attention is presently too focused on economics. Costs will stop innovation if TRL is low

D4 RENEWABLES INTEGRATION RECOMMENDATIONS

D4.1. Education, Research and Innovation

- Involve residents, property owners and citizens through activities and popular events
- Transfer knowledge from oil- and gas- based energy systems to sustainable approach and use of renewable resources
- Research the effectiveness of integrating and auctioning renewables
- Try to create test cases of solutions adapted to future legislation
- Work on standardisation and university representation at standardisation bodies
- Develop postgraduate studies including socio-economics for engineers, psychology for engineers, renewable energies for social scientists, etc. (as in MBAs)
- Research new materials (abundance, cost efficiency, environmental aspects)

D4.2. Social Cooperation and Outreach

- Fund wide multidisciplinary concepts
- Establish regular connections with communities: e.g. energy exhibits for local museums
- Gamify for behavioural impact and energy savings
- Use data to understand household behaviour
- Foster an international approach to renewables challenges, create an online community of interdisciplinary people

D4.3. Messages for Politicians

- Need for European quality criteria to address national boundaries
- Monitor the efficiency of the European Trading Scheme
- Adapt current policies to all user types
- Address the needs of all citizens, consumers and communities to avoid discrimination
- Develop European policies tackling behaviour
- Explore local/regional interaction
- Need for massive changes in the electricity sector (to decrease CO₂).
- Give importance to storage technologies
- Reflect on the importance of locale for the renewables mix. Heating, cooling and synthetic fuel production are important fields for the application of renewables.
- Transparent markets and clear policies are key
- Better North-South connections
- Need for a holistic approach: regulations, storage, grid integration, material, energy transition

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5th UNI-SET Energy Clustering Event

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- 24 See <https://www.eera-set.eu/eera-joint-programmes-jps/energy-systems-integration-2/> for more details
- 25 Available at <http://uni-set.eu/index.php/atlas>
- 26 <http://www.shapeenergy.eu/>
- 27 <http://uni-set.eu/index.php/events/clustering-events>



EUROPEAN **ATLAS** OF UNIVERSITIES IN **ENERGY** RESEARCH & EDUCATION

The European Atlas of Universities in Energy Research & Education is a result of the UNI-SET Universities Survey and contains information about several hundred energy research programmes and Master programmes in the field of energy. The research atlas also shows information about related doctoral schemes, if available. With the atlas, you can find key information on energy-related educational and research activities at universities throughout Europe.

You can use these maps to identify universities active in the different areas of the SET-Plan and in specific Fields of Education and Training and Fields of Science and Technology, covering the full spectrum of knowledge - from the typical science, engineering and technology fields, to economics, social sciences and humanities.

The European Atlas of Universities in Energy Research & Education is available at <http://atlas.uni-set.eu> and <http://energy.eua.be>.

About UNI-SET

The UNI-SET project supported the participation of universities in the SET-Plan process and in EU energy research and education in general. Coordinated by EUA, in partnership with KU Leuven and the universities in InnoEnergy, it mapped the activities of European universities in the energy field and produced an online, interactive tool that displays Master's, doctoral and research programmes related to the sector.

Additionally, the UNI-SET project surveyed potential energy field employers to gain insight into the current and future demand for professional skills and knowledge in the sector. Moreover, it organised six Energy Clustering Events addressing the key priorities of the SET-Plan and overarching topics. Some of the main outcomes of UNI-SET are:

- the “European Atlas of Universities in Energy Research & Education”;
- fifteen SET-Plan input papers;
- the “Roadmap for European Universities in Energy”;
- the report “Energy Transition and the Future of Energy Research, Innovation and Education: An Action Agenda for European Universities”;
- the report “Energy Research and Education at European Universities - The UNI-SET Universities Survey Report”

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