Integration of Power Transmission Grids (InGrid)

Prospects and Challenges at National and European Levels in advancing the energy transition

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1 Relevance for ENERGIX programme

This project will generate new knowledge on the energy transition in general and power transmission in particular. We will study the prospects and challenges related to the role of transmission grids in the sustainable restructuring of European countries' energy systems. The latter involves greater integration of energy systems and, especially, of transmission grids in Europe, which will be central to harvest the vast and yet untapped renewable energy potentials at larger distance from the centers of consumption. With our findings, we target policy makers, managers and the academic community. We make three major contributions. First, we will identify and explain the key prospects and challenges related to the integration of power transmission grids in Europe. Secondly, we will improve existing conceptual frameworks in the fields of innovation and policy studies to address the issue of grid transformation. On the combination of the former, we will finally sketch future avenues for policy making and infrastructure management to cope with the challenges. The intended work has the potential to strengthen the long-term economic value and efficient use of Norwegian renewable energy sources (particularly hydropower) as a complementary resource in the European electricity market, characterized by increasing shares of fluctuating renewable energy sources (wind, solar). Due to the project's focus on industry actors, it will also contribute to strengthening the Norwegian power transmission supplier industry. Strong linkages with the rapidly growing network in the field of sustainability transitions research, finally, will be beneficial for the Norwegian research community.

2 Aspects relating to the research project

2.1 Background, status of knowledge, and research gaps

This project has two main points of departure. The first is the culmination of two larger developments, the energy transition and European integration. Both have consequences for the transformation and European integration of power transmission. The second is about the conceptual challenges for the study of socio-technical transitions, especially with regard to governance issues, politics and technological complementarities.

ad 1: Europe's energy transition moves towards increasingly higher shares of variable renewable energy such as wind power and solar energy. Variable generation can be balanced by energy storage, including hydropower as the most mature option, and demand side management. Especially for the former, transmission will be central. In other words, transformation of transmission grids is a central piece in the restructuring of the energy sector. It is widely agreed though that transmission infrastructure policy, investment and transformation are significantly lagging behind changes in electricity generation, which creates tensions for the ongoing energy transition [1]. Key challenges include coordination across different countries and actors, ill-aligned regulatory regimes, lack of industry resources, immature technologies and systemic uncertainties [2], [3]. To address these issues, a number of projects and initiatives have been launched at the national and European level, including TYNDP, GRID+, e-Highway2050, EU Technology Platform, and others. Despite these activities major knowledge gaps remain on inter alia transnational planning tools, policy, evaluation methodology, and grid technologies [4] [5]. Also from a theoretical point of view, transmission issues still represent a comparatively neglected topic in the literature of innovation and transition studies. While much work exists on power generation and storage technologies, transmission infrastructure has received little to no attention in social sciences [2].

ad 2: Sectoral change and socio-technical transitions in general and the energy transition in particular are a core topic in the literature on innovation and sustainability transition studies [6]. The multi-level perspective [7], [8] and technological innovation systems [9], [10] have emerged as central frameworks to address the multi-dimensional issues of socio-technical transformation. However, there is still quite some potential for conceptual improvement. One central issue in this regard is the incorporation of politics and conflicting strategic interests of industry actors [11]. Another is about technological complementarities and transitions that span national boundaries [12].

In the political science literature, transnational governance and the associated challenges within policy processes are key issues. Although successful examples exist (e.g. in telecommunication), such initiatives have not been closely connected yet to the challenges arising from broader sectoral transitions. Increasing technological interdependencies have led to a greater need for policy integration, and so there is an important overlap between multilateral policy and socio-technical transitions. Further research will be needed on several issues, including the development of forums for political debate and assessment of transition initiatives, reform agendas for existing transnational agencies, or principles for new forms national participation in complex integrated missions.

What makes our topic very challenging is that the energy transition is characterized by a high degree of diversity at the national level, including different political priorities, different national electricity system structures, different natural, financial and human resources, different industry structures etc. At the same time, "energy integration" is taking place both as a consequence of global technology diffusion (e.g. wind power, smart grid technologies, energy storage, new transmission technologies) and as a result of international policy initiatives including the European integration, EU environmental policy targets (2020), EU energy policy etc. For this reason, we work with an international and interdisciplinary project team, through which expertise from different backgrounds can be combined.

2.2 Approaches, research questions, and methods

Socio-technical transitions and political integration are highly complex processes for which single disciplinary approaches will not suffice. For this reason, we combine concepts and methods from different disciplines including innovation and transition studies, political sciences and engineering. Our starting point is extant research in the field of innovation and sustainability transition studies [6], [13], which highlights that energy systems and markets are composed of both social and technical processes, which coevolve, or mutually shape one another, rather than one superseding the other [14], [15]. In other words, the electricity sector will be analyzed as a large socio-technical system that includes technological and material components as well as actors (utilities, technology suppliers, authorities etc.) and institutional structures (norms, standards, regulations etc.). The sector exhibits a number of particularities such as high capital-intensity, longevity of assets, high degree of regulation, high level of interrelatedness etc. that need to be taken into account [16], [17]. Transmission grid technology will then be viewed as a specific technological innovation system within the larger electricity system [2]. There are other related technological systems (on wind, hydro, PV, smart grids etc.) that come into play as well. Furthermore, transmission technology is subject to regulation, specific institutional structures and established policy regimes, both at the national and European level. Moreover, our focal system is populated by a broad range of actors, including transmission system operators and technology suppliers.

In order to account for national differences, and to incorporate potential developments in the related technological systems (e.g. offshore wind or storage), we will look at the situation in three countries around the North Sea: Norway, the United Kingdom and Germany. Norway is central due its large domestic hydropower and offshore wind potential, the UK is a European front-runner in electricity market liberalization, and Germany is the European leader in the energy transition. Moreover, all of these countries are characterized by (a) an extensive and continuously increasing use of renewable energy which causes challenges for grid connections, stability, management and investment for TSOs and policy makers; (b) the grids of these countries are connected via long subsea cables for which capacity increases are planned – the grid governance regimes interact, in other words; and (c) they are all strongly affected by policies and reforms emerging at the EU level. The selection allows us to transnational issues via comparative analyses and studying grid collaboration between countries, and how this, in turn, interacts with ongoing changes at the EU level. The following research questions (associated with work packages 2-5) will guide our analysis.

- What are the new challenges for national transmission grid governance (conflicting logics, policy regimes and strategic interests, integration of energy transition goals etc.)?
- How do novel regulatory and organizational developments at the EU level (e.g. ENTSO-E Connecting Europe Facility, Internal Electricity Market) impact on investment in and planning of power transmission projects?
- To what extent are new grid technologies emerging from the global supplier industry? Who are the key actors, their innovation networks and competences?
- To what extent do capacity bottlenecks in the European grid technology supplier industry threaten to block further transformation of transmission grids and diffusion of new technologies?

We will apply multiple methods, including case studies on selected transmission projects (successes and failures), patent analyses, bibliometric analyses, social network analyses, industry survey, and policy field analyses. Each of these issues will be presented in more detail in the individual WP descriptions.

2.2.1 WP1 – Theoretical framework and synthesis

This work package includes the development and refinement of the theoretical framework and a synthesis of the empirical studies. The empirical phenomenon we will analyze is highly complex and involves multiple dimensions, including innovation and technological change, policy making and institutional change, and firm strategies and industry development. To adequately address these different dimensions, we draw on two main strands of literature. First and foremost, we use the literature on innovation systems and socio-technical transitions [6], [7], [9], [11], which deals with fundamental changes in technological fields and broader sectors such as energy, transport, or food supply.

Through our analysis of the internationalization of transmission networks, the role of EU energy policy and market creation, and the dynamics of a global technology supplier industry we will contribute to a conceptual renewal of transitions research by incorporating international and political dimensions of infrastructure sectors, in particular how processes of market liberalization and globalization are reshaping transmission regimes in Norway and across Northern Europe. In doing so we will secondly draw theoretical connections with the literature on transnational governance, global environmental governance, and the emerging literature on the international political economy [18]–[20].

Task 1.1: Framework Development and Refinement: Review of established concepts from the innovation and governance studies literature. Identification of commonalities and conceptual linkages. Establishment of conceptual 'building blocks' and interfaces to guide the empirical studies. Ongoing conceptual refinement as a result of the empirical observations. Publication of working paper (incl. literature review results) and peer-reviewed conceptual paper.

Task 1.2: Synthesis and Policy Recommendations: Integration and critical discussion of the empirical results across work packages. Critical review in the light of existing literature. Compilation of policy recommendations. Publication of policy brief and peer-reviewed paper.

Interaction: WP1 closely interacts with all other work-packages throughout the entire duration of the project. Intense collaboration in the first and last year.

2.2.1 WP2 – The role of Institutional logics in National Transmission Grid Regimes for decision making and investment

In many European countries the electricity sector has been gradually privatized and 'liberalized' since the mid-1980s [21], [22]. These changes created new regulatory institutional configurations where formerly vertically integrated actors (electricity producers, TSOs, and regulators) were divided, and the dominant "logic" of the sector changed from one of "engineer system building" to one of "market-based cost efficiency" [23]. At the time of these changes several countries had accumulated excess transmission capacity. Focus on optimization combined with excess capacity resulted in investment stagnation and the beginning of an "asset sweating phase" [24]. In consequence, the transmission infrastructure in Europe is on the very end of its life cycle and needs major upgrading, even without an energy transition [25], [26]. While the "optimization" phase has induced innovation of new and improved services [21], it seems to conflicts with the need for new, major infrastructure investments by private actors [27]. At national level the situation thus constitutes an institutional misalignment between short term optimization and longer term energy security as assets depreciate. This is further augmented by new transmission needs to accommodate a renewable energy transition.

Preliminary research suggests that the institutional logic of "short-term cost-efficiency" is being challenged in Norway by other criteria for investment decisions [28]. There are, across Europe, strong indications that "engineer system building" logic is growing in strength to counteract asset depreciation, and accommodate renewable energy expansion. WP2 follows up on these preliminary results and conduct more in-depth analysis.

By use of the concepts of socio-technical regimes [10] and institutional logics [29], [30], WP2 explores the potential tensions between "logics" across the three case study countries between which interconnector cables exist and/or are in process of being built. We conceptualize national grid regimes as those sets of actors and institutions that interact to shape the direction of change in transmission grid management which includes long term strategies and criteria for investment decisions.

Task 2.1: First analytical step is to map national regimes in each country. The central actors are TSOs, public energy agencies responsible for coordination and regulation , and central government bodies . In the preliminary mapping of grid regimes we focus on key issues such as relationships between industry and government, the model of energy market liberalization adopted, the regulatory frameworks governing the operation and expansion of energy infrastructure and the how the wider governance framework for energy transitions is influencing transmission regimes.

Task 2.2: Second analytical step is to conduct a detailed cross-case analysis of the national transmission regimes in the case study countries, Through a structured comparative analysis analyze how policies and regulatory frameworks are emerging to incentivize new transmission investment, the political contestations and tensions that are arising and how tradeoffs between the "short-term cost-efficiency" and "engineer system building" logics are being resolved. As empirical material we use grid development plans, government white papers, cost benefit analysis reports on interconnectors, annual reports by TSOs, media coverage material, and in-depth interviews with central actors. The "need" for transmission is estimated on basis of a review of a range of transition scenarios published by important national and international organizations; see WP5.

Interactions: WP2 interacts with the EU-level issues discussed in WP3. Also, institutional logics impact on technological development via TSO preferences and decision making (WP4). Interactions will be explored in synthesizing work (WP1).

2.2.2 WP3 – European market integration and the internationalization of transmission regimes

The key aim of this work package is to analyze the emergence and evolution of the EU's *Internal Electricity Market* (IEM) and the electricity transmission infrastructure that is likely to be needed to underpin this market. In investigating the development of the IEM, our aim is to understand and translate European-wide developments including short term day-ahead wholesale markets, longer term capacity markets, infrastructure development, system balancing and reserve, and transmission investment. Although not a full member of the EU Norway has played a key role in developing and implementing the IEM and the European market will influence greatly the future shape of the Scandinavian and Northern European regional electricity markets.

In recent years the policy priorities for the IEM have shifted somewhat towards investment in interconnectors and the need to increase the capacity of national transmission grids to deal with the increasing volume of traded electricity across international borders. There has been concern that market signals alone will be inadequate to deliver the necessary levels of transmission and interconnector investment and that a long term strategic approach may be required more in line with an "engineer system building" logic. The IEM is part of wider activities at the EU level. The European Commission is now developing an energy infrastructure policy that integrates climate and energy goals where the focus is on a trans-European transmission infrastructure capable of accommodating the penetration of a renewable production consistent with affordable and reliable energy supplies [31]. Symptoms of these activities are the *"Energy infrastructure priorities for 2020 and beyond"* document, Projects of Common Interest (PCI), Connecting Europe Facility (CEF), the *"Long-term infrastructure vision for Europe and beyond"* [32], and ENTSO-E's (European Network of Transmission System Operators) Ten-Year Network Development Plans (TYNDP). We interpret IEM developments in light of this wider context.

Task 3.1: The first task will be to provide an overview of key political, economic and technological developments which have shaped the recent history of IEM in recent years (mid 2000s). The initial phase of IEM development saw the emergence of Regional Initiatives [33]; since then, efforts have been made to develop a single trading arrangement between IEM pricing zones with the aim of optimizing electricity flows between previously separate market zones. Through a series of expert interviews and analysis of key actors (such as ENTSO-E and ACER), and of policy and strategy documents the research will examine conflicts and synergies between the "cost-efficiency" logic embedded in the IEM and the increasingly influential "engineer system building" logic associated with efforts to create the conditions for new transmission investment across Europe.

Task 3.2: Through an in-depth case study analysis of the development of a North Sea 'Supergrid', the second task is to examine how processes at the EU level are influencing specific developments at the national transmission regime level in the Norweigan, UK and German contexts. Drawing on interviews and documentary analysis the case study focus on how actors are navigating a complex political and market environment to create the investment case for new interconnector investments (such as the NSN link which would be the largest subsea electricity interconnector in the world).

Interaction: Task 3.2 will also draw on the emerging outputs of the national level case studies in WP2. The outputs of this European level analysis will inform the analysis of technology diffusion and industrial capacity in WP4 and WP5.

2.2.3 WP4 – Innovation networks in the grid technology supplier industry

The technology supplier industry for power grids is relatively small, highly specialized, and predominantly global. Central actors in the industry are inter alia Siemens, ABB, and Alstom (power electronics) and cable/wire producers and installers e.g. Prysmian and Nexans.

However, the supplier industry is now both diversifying and growing as new technologies diffuse in the grids. First, new entrants emerging from Asia are expected due to existing bottlenecks (see WP5). The prominence of the Chinese Electric Power Research Institute as patent holder in HVDC (high voltage direct current) is indicator of Asian activity in grid technologies. Second, ICT companies are entering as technology suppliers as the power grids become "smarter" [34]. Third, there are also new entrants from offshore oil and gas (predominantly from UK and Norway) entering installation and maintenance service for offshore grids [35], [36].

We know that much technological innovation is taking place in grid technologies with the most prominent area being HVDC technology [2]. Despite advances, grid technologies still have vast development opportunities [37], [38] that may possibly re-open the "battle of currents" [39] and, in turn, have disruptive impacts on the supplier industry.

Given the potentially central role of transformation of power grids for the energy transition in Europe, it is important to understand in more detail the direction and extent of generation and diffusion of new grid technologies. Currently, there are, to our knowledge, no industry and innovation studies of the grid technology supplier industry.

The fundamental perspective is that technological innovation processes are a collective phenomenon that emerges and develops over considerable time periods. Successful innovation processes rely on input from a range of specialized firms and considerable support from public organizations, meaning that innovation processes invoke the use of large scientific-technological networks.

We will map (where they are) and analyze (how they have developed recently) these *Global Innovation Networks* [40] in the grid technology supplier industry by use of patent data, bibliometric data, and advanced social network analysis.

Task 4.1: First analytical step is to methodologically define a new technological field in terms of patent clusters. Transmission grid technologies do not exist as a category in current classifications. We will by use of expert interviews compile relevant technology codes to get an accurate representation of transmission grid technologies.

Task 4.2: Patstat (the EPO Worldwide Patent Statistical database) will be used to analyze grid technology patents and their evolution over time. Such data are often used as indicators of technological knowledge flows (spillovers) among different agents. NIFU has access to the most recent version of Patstat and will use the database for the patent analysis. We will identify main applicants based on Patstat information.

Task 4.3: The bibliometric analysis will be based on a matching of two databases, INSPEC and Scopus. The Inspec database contains over 14 million bibliographic and indexed records to the global research literature on physics and engineering, among others specialized in electrical engineering & electronics, computers & control and ICT. We will use the Inspec Classification and the Inspec Thesaurus to identify relevant publications. Because Inspec provides the institutional affiliation only for the first author, we will match this data with Scopus from where full information on institutional affiliation will be retrieved. TIK has access to this data.

Task 4.4: We combine the information regarding patent applicants and authors' affiliations to analyze these via social network analysis.

2.2.4 WP5 – Capacity bottlenecks in grid technology Supplier Industry

The grid technology supplier industry is small, highly specialized, and is currently facing major market growth as renewable energy deployment grows. The primary limitation to such growth seems to be the capacity of the industrial value chain to deliver [41]. For example, there is a limited number of suppliers of subsea power cables, and the demand is currently outpacing manufacturing capacity [42], [43]. In relation to the grid development plan 2014, Statnett reports that within the last year capacity constraints in the technology supplier industry led to higher prices and significant delivery delays [44]. In power electronics, the frontier of HVDC technology is yet to be tested beyond the design stage, and capacity is uncertain [45], [46]. There is a limited capacity for laying vessels for installing subsea grid systems which severely augments total cost [47].

At the same time the 2012 Ten Year Network Development Plan (TYNDP) by ENTSO-E identifies a need for about 52,300[1] km of new or upgraded HV routes before 2022, where approximately 39,000 km will use HVAC, while 12,600 km, mainly subsea, will be HVDC. Total investments costs are estimated at €104 billion, with €23 billion for subsea cables [48]. These estimates have been criticized for being conservative [49] as they do not assume realization of EU renewable energy goals for 2020.In addition, the TYNDP doesn't include purely national investments and expansions in power grids such as connecting renewable energy sources and general upgrading. The TYNDP estimates are thus likely to be quite conservative. Globally, there are plans for building about a 120,000 km HVDC (mainly in China) before 2020 [50].

In this context a central issue becomes one of timely upscaling of capacity amidst a market growing more in speed and volume than was expected in the industry only a few years back [51]. The extent of such bottlenecks is currently unclear and it casts doubts on the industry's capacity to deliver *in due time* which, in turn, may hold back and increase cost of transforming the power grids. We propose to identify and assess these capacity bottlenecks in Europe in terms of competences and human capital, financial resources, and other complementary assets [9].

Task 5.1: We estimate future demand for grid technologies by compiling a combination of national and international low carbon transition scenarios (including grid development plans) developed by for example IEA, EU, or Green Peace for 2020 and 2030, respectively. We develop very rough proxies for e.g. how many engineers a cable producer needs per 10 km offshore grid, see [52]. We will extend this analysis to include other parts of value chain.

Task 5.2: We estimate the current capacity in the European supplier industry. We will search for data on production, investment and employment growth. The companies identified in WP4 are main population but we will "test" representativeness of population via interviews with industry experts and industry associations (e.g. Europacable). Many are listed at stock exchanges, and we will have access to yearly reports. Also, information is available via media coverage.

Task 5.3: We then use the database of innovation networks, developed in WP4, to design and conduct an interview-based survey of the supplier industry. We present companies with scenarios and proxies. We ask them to asses such resource demands, and to identify main challenges for companies to develop capacity in due time. Results will be indicative of major industrial and innovation policy challenges in grid transformation.

2.3 Project participants

The project is a collaborative venture between the research institutions organizations listed in the table below. TIK will head and co-ordinate the project with Research Fellow/postdoc Allan Dahl Andersen as project coordinator with responsibility for coordinating the work across WPs and following up milestones.

Organization	**Researchers**	**Abbreviation**
ETH Zurich	Jochen Markard	JM
University of Edinburgh	Ronan Bolton	RB
Nordic Institute for Studies in Innovation, Research and Education (NIFU)	Antje Klitkou	AK
Centre for Technology, Innovation and Culture (TIK) at the University of Oslo	Allan Dahl Andersen Olav Wicken	ADA OW
Center for International Climate and Environmental Research (CICERO)	Anne Therese Gullberg	ATG

[1] Compared to the existing grid length of about 305,000 km.

3 References

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