Internship/PhD proposal 2024/2025

Collaboration SPEC/LIED

SUJET

Network structures and development dynamics - from the Industrial Revolution to the Energy Transition

Structures des réseaux et dynamiques de développement - de la révolution industrielle à la transition énergétique

SUMMARY

Networks are crucial components of complex societies and underlie successful climate-energy strategies. Nevertheless they remain relatively understudied and insufficiently understood in their dynamics as well as in their relation to resource consumption and economic prosperity.
In this doctoral project, several historical cases of physical network will be explored from an industrial ecology standpoint and in relation to energy consumption. The project will address complexity in sociotechnical network structures and uses based on a complex systems modelling approach associating statistical physics (graph theory), geography and economic history. The project will mainly focus on the transportation and energy networks and their entanglement.

A first target will be railway networks that progressively grew during the 19th century in relation to coal extraction, trade and use. Railway networks are intertwined with early-industrial sociotechnical development and paved the way to the development of road networks in the 20th century in particular on the basis of complex oil networks. The study will address the dual role of railways and road networks in the transportation of both passengers and freight of energy and materials. The growth rates, interconnections and key metrics of these networks will be jointly analyzed and compared to an equivalent analysis of electricity grids which are currently under study by members of the internship/PhD proposal team.

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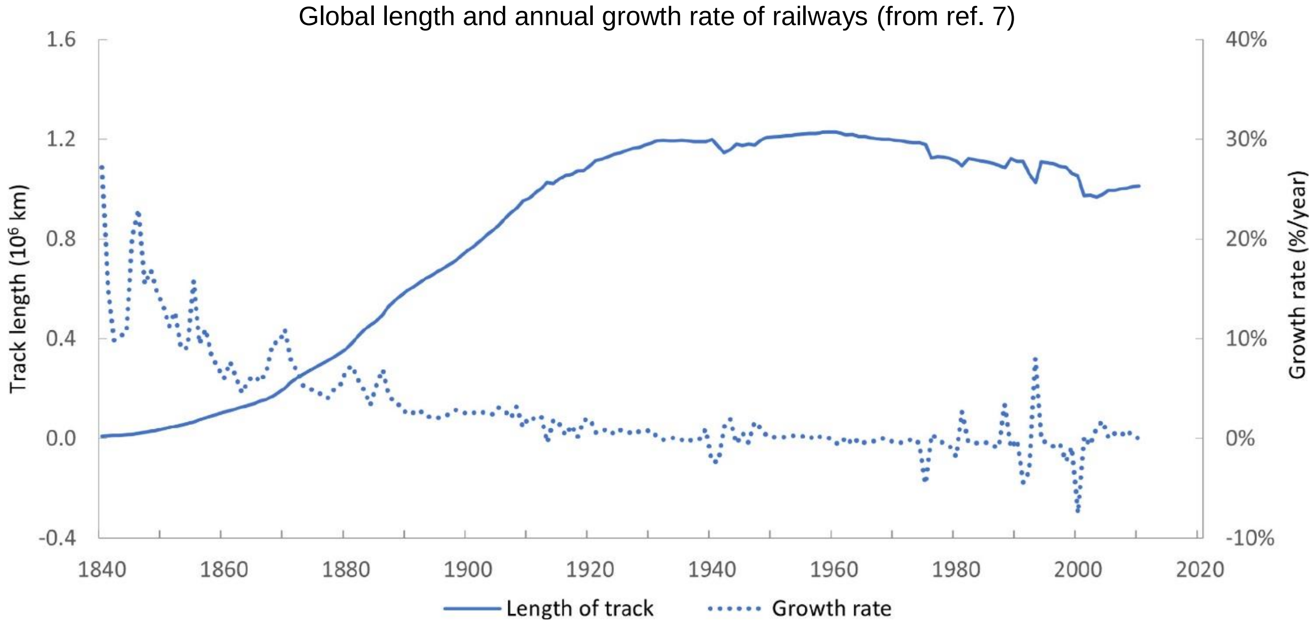
SOME ARGUMENTS

As the energy transition to a zero net emission society gets underway, attempts are being made to estimate the associated costs [1], as well as the impacts of technology deployment on the use of natural resources, particularly for energy investments [2]. The development of energy transmission and distribution networks is often a blind spot in forecasts, even though they are recognized as central to the use of low-carbon energy sources [3, 4]. A PhD project is presently applying graph theory tools to the electricity network [5]. The topological description can then be complemented with a quantitative assessment of the physical resources invested in the network elements (lines, transformers, local stations), allowing a comprehensive knowledge of the material and energy footprint of the network evolution.

Since electrification is, together with zero-carbon electricity production, a major component of a successful transition towards zero-emission [4], it is necessary to understand and develop the capacity of electricity to fuel the infrastructure (grid building, maintenance and decommissioning). The main idea of the present project is to explore past examples of network development, singling out cases where an energy source was at the same time instrumental in the construction of the network elements and a beneficiary of its growth.

We will take as first historical case the development of the railway network in the 19th century. The coal-iron-railway *development block* is a central ingredient of the European industrial revolution [6]. Rail transport is the subject of a new research interest [7]. We aim at understanding the link between the dynamics of transport development (see figure below) and economic growth based on coal consumption. Coal (and iron ore as well) is both a raw material for network construction and operation, and a major beneficiary of its own development through the intensification of long distance trade, at national, regional or global levels [7, 8].

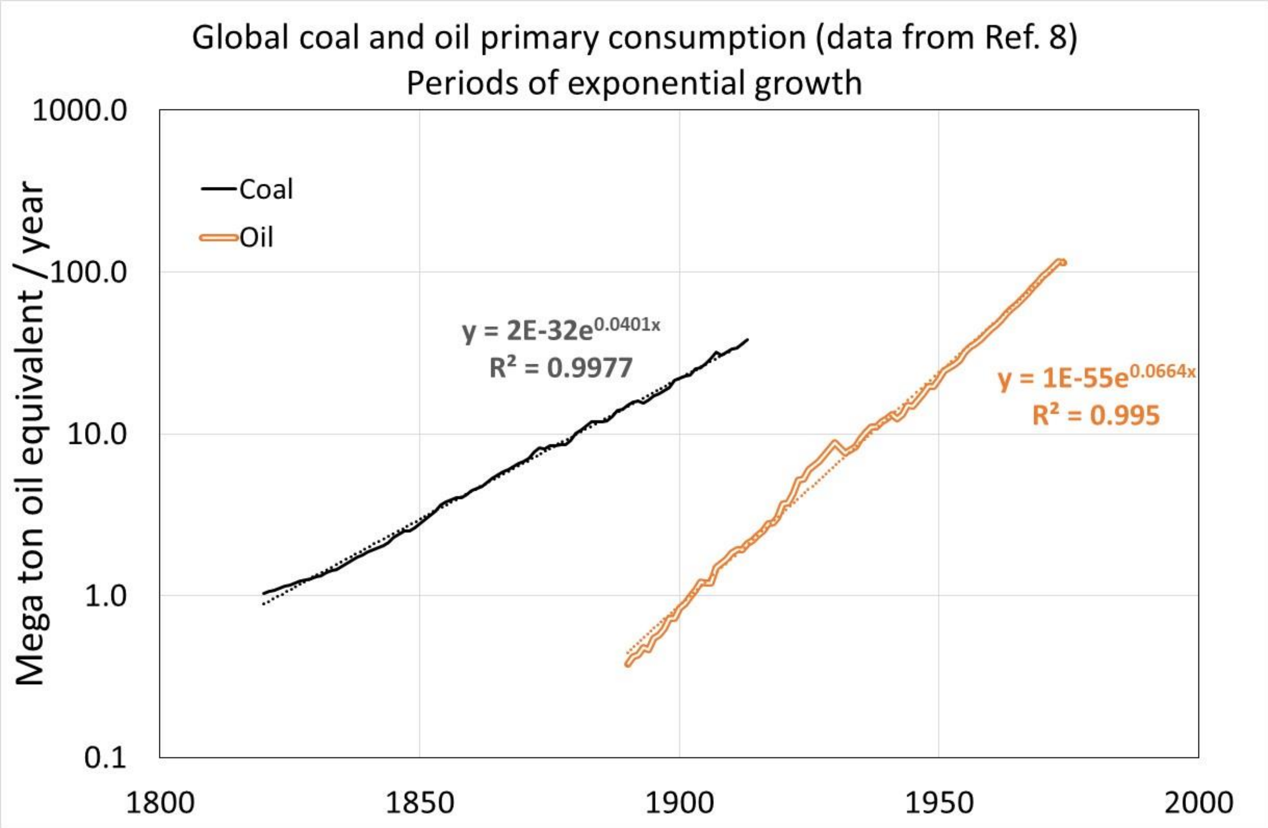


We will make use of the results already obtained by graph theory applied to these spatial networks [9, 10], and will draw on a similar approach underway for electricity networks [Ref. 5, and further results of E. Emery's doctoral studies]. In addition to materials, rail development was also a major driver of passenger transportation. It will be useful to compare the growth of national and international railways, which are mainly driven by industrial and commercial activities (coal and other materials), to urban railways, which patterns are, in contrast, essentially devoted to passenger transport.

Other examples of networks will also be explored, with the aim to identify and simulate general key patterns and interconnections in networks development. To this regard, the motorway system is an interesting candidate as it is intimately coupled to the deployment of oil-based technologies and infrastructures including pipelines, refineries and distribution.

A first comparison of coal and oil consumption dynamics in the long-run indicates an intriguing phenomenon, evidenced in the figure below: coal in the 19th century (1820-1914) and oil in the 20th, each in their period of dominance, follow a steady exponential growth curve. However, coal grew at an average annual rate of 4%/year whereas oil shows a higher rate of 6.6%/year. Could the long-run exponential growth and the different rates be explained by a model including both network topology and material requirements of its deployment and exploitation?

For the selected study areas, the internship/PhD program will include data gathering and compilation with already available datasets and will focus on developing a complex system modeling approach of networks dynamics in relation to energy and material components.



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