NGI101x - Getting to know the concepts

Hello everyone and welcome back. In this video we will introduce you to the basic concepts we use in discussing the socio-technical complexity of infrastructure systems.

For this purpose we have provided a glossary of important terms that we use throughout the course. Please read through that list and familiarize yourself with these terms and what they mean.

What you should first wonder about is: what is the definition of infrastructure – or: what is a useful definition of infrastructure?

If you think about infrastructures, the first thing that probably comes to mind is a highway or a railroad network, or any other large scale technological system. Imagine cables, pipelines, roads or rail that interconnect things like people, buildings and cities. The scale of this system may be:

regional, as in the case of drinking water and sewage infrastructure. However, most of today's infrastructure systems cross national borders.

They span entire continents or even the globe. Think of electricity infrastructures,

and of course telecommunication infrastructures and the internet.

If your focus is on the physical reality, then you will appreciate infrastructures as truly impressive feats of engineering. They are the megastructures of modern times. Infrastructures are incredibly complex physical networks, composed of millions of links and nodes. We can also think of the technological expert knowledge that we need to design, build, maintain and operate these infrastructures. Without science and engineering knowledge, infrastructures could never have been brought into being. They physically manifest themselves in our landscape in the form of roads, railways, airports and seaports, overhead lines and other capital intensive hardware.

However, the technological or physical dimension is only part of the story of infrastructure. A social scientist studying infrastructure will see a social system, in which millions of users are interconnected. He will also see a system that connects the producers and users of a specific service. What the social scientist sees is as relevant as what the engineering scientist sees.

So infrastructures have a physical and a social dimension.

Even if, for the sake of scientific analysis, we tend to separate the two dimensions, they cannot be separated in practice. For example, car owners are not likely to switch to electric vehicles if they cost much more than a conventional vehicle, or if there are only limited means for charging them. One of our challenges in this course is therefore to understand infrastructures as socio-technical systems. In such systems, a complex physical network is intertwined with a complex social network.

Each infrastructure system was brought into being to provide a specific service that we consider essential for our well-being, for socio-economic development. The provision of safe drinking water and the treatment of waste water and solid wastes are essential for public health. Infrastructures for mobility of people and goods have allowed us to explore the world. They have expanded markets and enabled global trade. In modern societies everything depends on the uninterrupted supply of electricity, communication and information services.

In fact, infrastructure related services are so essential, that national governments take responsibility for the accessibility, availability, affordability and social acceptability of these services. This may imply that the infrastructure is owned and operated by a government body. However, as we will see, there are alternative ways to ensure the reliability and quality of infrastructure related services.

Let us take the example of the electricity infrastructure.

The first true electricity infrastructure came online in 1882. It consisted of a single coal fired generator providing power to the light bulbs of 59 customers within a New York neighborhood. Soon, similar systems sprouted in major cities around the world. Eventually, these systems were expanded to link entire urban areas with a diversity of electrical devices and multiple generators operating simultaneously. Gradually, these isolated grids were linked to provide backup power and improve stability. They were extended to connect progressively larger and more remote power generation facilities. Today's electricity infrastructures link these formerly separate networks into national and supra-national power systems. Moreover, these power systems are fed by an increasingly powerful and technologically diverse array of generators delivering electricity for our daily needs.

Throughout most of the 20th century, the key tasks of electricity generation, transmission, distribution and supply were concentrated within a single organization per country. A so-called vertically integrated utility. In many countries this single organization was a public monopoly. In the case of a private monopoly, it was heavily regulated by the government to safeguard affordability, availability, safety and other public values.

In recent decades, however, processes of infrastructure reform have induced so-called vertical unbundling of the electricity value chain. In many countries, power generation has largely been privatized and now takes place in a competitive market. Similarly, energy wholesale and even energy retail markets have in many countries been opened up to competition. With these markets, new players have entered the scene, such as market operators, traders and brokers. In between power generation and supply to end-users is the transport over grids. These grids are still owned, operated and planned by monopolistic system operators. They are known as TSOs – transmission system operators – and DSOs – distribution system operators.

Why is there no competition between electricity grids? This is because the grid is a natural monopoly. The existing infrastructure network was established over many decades and therefore represents a massive capital cost. The cost of building a competing grid is simply too high. This is the case for many infrastructure networks, however …. new technologies may change that picture. In the world of information and telecommunication services, for example, we have seen competing networks come up over the past two decades, both fixed and wireless networks.

As you can see, the social system has become much more complex as a consequence of electricity infrastructure reform. Meanwhile, in the electricity infrastructure, new technologies are being introduced, for example to farm wind and solar power.

The scale of power generation is also changing.

Many consumers of electricity have become producers at the same time. Think of consumers' solar panels on their roofs or small scale units for the cogeneration of heat and power. Consumers have actually become prosumers of electricity. These technological changes can endanger the stability of the grid.

To make sure that doesn't happen, operational practices need to be revised and new rules need to be implemented. This is another example of how the social and the technical dimensions of the electricity infrastructure are intertwined.

Infrastructures become even more fascinating if you realize that most of these systems have slowly interconnected local, regional and national systems over several decades or even centuries. That implies that they were not designed as the integrated systems that we know today. Rather than being designed, they evolved as integrated large-scale systems. We do, however, expect them to function as integrated systems, offering adequate service at all times, wherever we are.

The reality, unfortunately, is that we cannot take the availability of these services for granted, as many people in developing and emerging economies know very well. Women and children in sub-Saharan Africa spend many hours a day to get water and to collect the firewood they need for cooking.

In a city like Bangalore, India, which is the heart of India's IT industry, planned interruptions of drinking water and electrical power supply are common. The city's infrastructures cannot keep up with the massive influx of new citizens and the fast growth of the economy. We are still a long way from ensuring reliable water, energy and transportation services for the whole world.

And, even when advanced infrastructure is available, we are struggling to adapt our legacy systems to changing demands and preferences of individual users and their societies. Local infrastructure failure may have mundane causes such as wear and tear, or digging contractors accidentally hitting a pipeline or a cable. Even the occasional power blackout may hit us right here, as a consequence of a failure somewhere far away that cascades through a continental network. And, to further complicate matters, failures may also originate from other infrastructure systems. This is because today's infrastructure systems are largely interdependent. Drinking water infrastructure needs electricity to power its pumps. Continental electricity infrastructure needs telecom and information infrastructure. Without it essential information on the state of the network cannot be shared between national Transmission System Operators. Mobile telecommunication infrastructure critically depends on electricity. In other words , we are dealing with a system of interdependent infrastructure systems.

The socio-technical complexity of modern infrastructure is unprecedented – which is one of the reasons why we refer to Next Generation Infrastructure. The need to deal with that complexity is a given. After all, how else are we to supply the next generation of the world population with infrastructure services?

We will use the conceptual framework of Complex Adaptive Systems to capture the dynamics of infrastructure systems. These dynamics become clear when looking at the operational time scales and evolutionary time scales of infrastructure systems. Complex Adaptive Systems theory will help us understand how changes in interactions between decision makers gives rise to unpredictable and possibly undesired behavior of the system as a whole.

In week 2 we will introduce complexity theory.

Eventually, we will show you how the development and services of infrastructures depend on the decisions of many different actors in the system: investors, owners, operators, regulators, policy makers and users. More importantly, we will show you how incentives and regulations shape those decisions. You will learn to not underestimate the power you have, as a user, with millions of other users, to change the pathways of infrastructure development.

Thank you for your attention. The next weblecture is an animation which will also help you to understand the complexity of infrastructures.