Summary

The current energy supply system seems to be self-evident. However, a lot of signals indicate that the present energy supply needs a fundamental change. Some of these signals are:

- Climate signals
  Due to the use of coal, oil and gas, large amounts of carbon-dioxide (CO_2) are brought into the atmosphere, with consequences for global warming and climatologic changes, like rising of the sea-level, more extremes between wet and dry territories, etc.

- Economical signals
  Oil and gas prices seriously increased during the past years. Worldwide, a continuous rise in the need for energy can be observed. However, the reserves of oil and natural gas are decreasing and it is becoming more and more difficult to reach them. Scarcity of natural resources arises with serious consequences for the price levels.

- Geopolitical signals
  The supply of oil and gas is becoming less certain. Most of the industrialised countries do not have enough reserves in the long term to supply their own energy demand. Some countries with large reserves sometimes use energy as a means of exercising political power.

The answer to these converging trends is a transition towards a (worldwide) sustainable energy supply system. This means less waste of energy. It also means that energy should be retrieved from other sources: less oil, coal and gas and more hydro, sun, wind and biomass. This fundamental change offers large opportunities and challenges. Such a fundamental change or energy transition is expected to endure much more than one generation. To explore this transition a set of three different transition paths has been explored.

In this study, the focus is laid on the consequences for the electricity networks in the Netherlands when the developments mentioned before are steadily realised. The main objective of this study is the identification of the effects of possible transition paths for electricity networks. The following main research question has been addressed: *How will the Dutch electricity networks develop in far future (2050)?*

The architecture of the different transition paths is developed around three diverging scenarios, namely:

- Towards Super Grids
  In this scenario, it is assumed that the average unit size increases considerably. All generation units are assumed to be connected to the extra high voltage (EHV) or high voltage (HV) transmission levels. In order to achieve that 50% of the electricity consumption has sustainable origins, the emphasis is laid on imports of large volumes of biomass, which are burnt in large scale biomass (gasification) units (70 TWh), large wind farms at the North sea (22 TWh) as well as on sustainable imports (8 TWh).

- Towards Hybrid Grids
  In this scenario, it is assumed that the average unit size decreases. On the one hand a few large scale units feed in at the highest voltage levels. On the other hand, a lot of small scale units feed in at the lower voltage distribution levels. In order to achieve that 50% of the electricity consumption has sustainable origins, the emphasis is laid on large offshore wind farms (42 TWh) and large scale biomass power plants (32,5 TWh). The remaining part of sustainable electricity is assumed to be produced by PV panels in the built environment (12 TWh), small scale biomass power plants (10 TWh) and onshore wind farms (3,5 TWh).

- Towards Local Grids
  In this scenario, it is assumed that the average unit size decreases considerably. The main emphasis is laid on local electricity generation. Nevertheless, also large scale generation units appear to be necessary in order to supply main (industrial) load centres and in order to match the complete energy balance. In order to achieve that 50% of the electricity consumption has sustainable origins, the emphasis is again laid on offshore wind farms (52,5 TWh). The remaining part of sustainable electricity is assumed to be produced at local scale by PV panels in the built environment (24 TWh), small scale biomass power plants (20 TWh) and onshore wind farms (3,5 TWh).

The research into the future development of electricity networks resulted in the following conclusions:

1. Electricity networks remain necessary, not only due the advantages of high reliability and less reserve generation capacity, but also for system balancing purposes and from the viewpoint of the opportunities of one interconnected free European electricity market.

2. Developments in demand on the one hand and supply on the other hand determine the transition road to the electricity network of the future. For the demand side the demand allocation, growth and profiles are of great importance. For the supply side, choices for the primary energy mix are important (which determine the unit size, utilisation degree, controllability characteristics and simultaneousness of production of the generation sources). Due to the expected growth of the electricity consumption, all primary energy options should be seriously taken into account.

3. Electricity networks have a promising perspective, but the networks of the future will not be the same as the present ones. Especially the medium and low voltage distribution grids are expected to change fundamentally. They will gain more and more characteristics that belong presently exclusively to (extra) high voltage transmission grids. In the future, more balancing mechanisms are expected to be needed and the issue of system balancing will probably (partially) be solved at the lower voltage levels. Especially, if the amount of DG further increases, it becomes desirable or even inevitable that system balancing will not longer be solved by the TSO at the highest voltage levels only, but that it will also be (partially) solved by regional network operators.

4. Within the same frame of objectives for a sustainable electricity supply in the future, various solutions can be imagined with different outcomes for the electricity networks. In scenario Towards Super Grids the emphasis is laid on large scale biomass power plants, while in scenario Towards Local Grids the emphasis is laid on local solar energy and offshore wind energy. The scenario Towards Hybrid Grids is a combination of both previous scenarios. Each scenario meets the assumed goal of 50% sustainable electricity in 2050, but the consequences for the networks are quite different.

5. The primary energy mix for electricity supply in the future determines the development of the networks to a great extent. The choices to be made for the primary energy mix of the future do not only determine the unit size and the voltage level for connecting the generators but they determine also the controllability and the simultaneousness of power production. Both aspects have serious consequences for both network integration and system integration.

6. The road to a sustainable power supply system entails new issues and offers large opportunities and challenges for engineers. These can be attributed to three major categories or dimensions, namely: 1) network integration, 2) system integration and 3) new technology.

7. Considering the dimension of network integration, more network capacity is expected to be needed. Depending on the choices for the primary energy mix, additional network capacity at different voltage levels may be expected.

8. Considering the dimension of system integration, a need for more balancing facilities and mechanisms is foreseen. The amount of this need depends on the choices for the primary energy mix. In the ultimate case, a paradigm shift seems to be inevitable from the present situation of matching supply to demand to a new situation of matching demand to supply.

9. Considering the technology dimension, new and innovative technology will ensure that electricity networks of the future will be different from the networks of the past and the present. A steady and gradual integration of 1) energy, 2) ICT and 3) power electronics is expected to take place, leading to one efficient, flexible, dynamic, intelligent and self controlling interconnected system.