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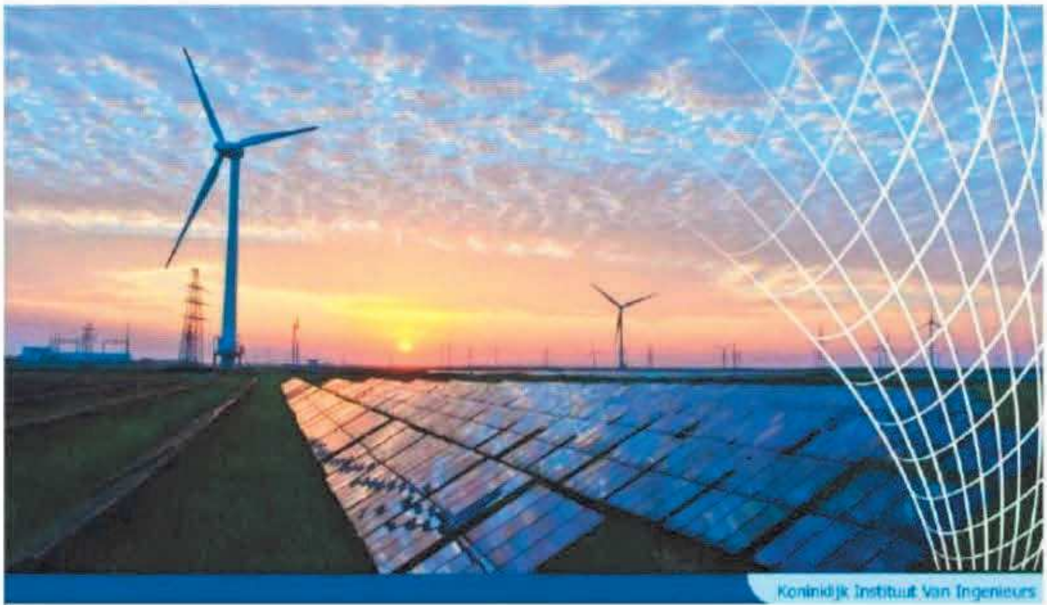

Design of a Dutch carbon-free energy system

EnergyNL2050

A detailed follow-up study

with system simulations and

a financial analysis

May 2020

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Summary

From 2013 till 2017 we organized several KIVI seminars in Utrecht where more than 50 Dutch professionals presented their views on the energy challenge for the Netherlands in the future. Based on this particularly useful information we devised an energy plan for 2050 and published it beginning 2018.
The plan describes the EnergyNL2050 energy system which is CO_2 neutral. The system generates more than 85% of the nationally needed energy and needs at most 15% import from abroad. Although positive feedback was received, we recognized that a few important aspects were still missing, such as hourly based system simulations and a thorough financial analysis. In this paper we report the results of detailed simulations using hourly weather data, renewable energy production and demand data during three years. Recent functional energy demands (year 2015) were extrapolated to the energy demands expected in 2050. From this the required renewable energy could be analyzed.
The simulation results give ample confidence that the system can work.
We also refined the system design such that all components cooperate well together to achieve an optimal final result. A detailed financial analysis shows that the EnergyNL2050 system is affordable: the annual energy costs are analyzed to be about €28 billion. The current annual energy costs are about €21 billion. But this cost difference is compensated by the avoided CO_2 tax (being €41 per ton CO_2) on the 185 Mton saved CO_2 emission.
The EnergyNL2050 system is a long-term outlook, focusing on 2050. This paper reports verification of our earlier results and describes the implementation of the system and in particular the steps that need to be taken in the near future. The results are presented in the last section of this paper. It addresses the main issue which is: how to match the variable supply of energy with the different demands of the future. We complete the paper with a series of policy issues that the government should work on.

The main facts of this energy plan

As already stated in the title the plan is completely CO_2 neutral, and this without the use of biomass , synthetic gas, fossil fuels and the use of geothermal heat. The energy needs for heating, transport and industry are satisfied mostly by electricity and hydrogen is used as chemical feedstock for industry and to supply backup power. Hydrogen is produced by a series of large scale electrolyzers. Backup power is provided by a distributed network of fuel cells and they also provide additional power in case of very cold weather. Batteries are used as short term storage to match the variability of wind and sun with electricity demands and the efficient operation of the electrolyzers. The plan can satisfy almost completely in the energy needs and needs only a very small amount of import. Often it is claimed that import may be cheaper, but our analysis shows that this is not the case. In the implementation care is taken that the Dutch landscape is preserved as much as possible by proposing only a very limited amount of wind power on land and only a very small amount of solar parks. One important feature also is that the electricity network does not need a significant capacity enlargement by using several interesting techniques such as smart charging, a distributed net of fuel cells, an efficient curtailment strategy and the location of the electrolyzers. The total cost of the system has been modelled and the plan is derived from a total cost optimization of the entire system, including the different segments of the electricity grid.

1. Introduction

In 2018 we published in the white paper “EnergyNL2050” the results of our study on a full carbon free Dutch energy system 2050. Vision and approach to the study are carefully described in the paper. A clear overview of the 2050 energy system was presented (Persoon et al. 2017).
EnergyNL2050 from KIVI is one of the systems analyzed by Berenschot in 2018 in the report on system options as input for the Dutch Climate Agreement (Den Ouden et al. 2018).
We were able to obtain a good mix of renewable energy sources: Wind power onshore and offshore, PV-electricity, some other renewables and some imported electricity, covering most of the energy demands. We were able to get a rough estimate of the minimal required backup electricity. However we did not have tools for studying the reliability of the energy supply chain, covering the demands on an hourly basis!
But Koen Huizer (KIVI-Electrical Engineering) who joined our study team, was able to develop the required tools. With his software tools the energyNL2050 system could be simulated, using the hourly data for PV and wind electricity. These new possibilities have led to this follow up study. In part 3 of this study the simulation results are carefully analyzed and are also extended with a financial analysis, aiming to obtain an optimal 2050 NL Energy System based on minimal annual energy costs.
The approach for our study on the carbon free energy system, as explained in the white paper, has not been changed: basic conditions, like a 100 % carbon free energy system, no carbon capture and storage (CCS), no nuclear energy and biomass as part of the mix of energy sources, and the analysis of the energy demands in 2050 are still the same. Also the full decarbonation of the energy demands with electricity and hydrogen as the main energy carriers are conditions that have not changed. The energy system is such that the Netherlands is largely self-sufficient for its energy.
The analysis shows, among other results, that a well-balanced backup system, based on H_2-fuel cells for re-electrification, will cover the electricity demands also in longer periods with low wind and solar conditions, the so called “Dunkelflaute”.
The system simulation results however in higher figures for curtailment and backup output: **Curtailment** is now 6 TWh annually compared with the 2 TWh as originally mentioned in the 2018 white paper and **Backup output** now requires 16 TWh annually, where as we expected 12 TWh in the 2018 white paper.

Cost calculations for the 2050 energy system are also included, see part 4. Based on those simulations and projected prizes several financial data are derived, giving an insight in the total cost of the system and enabling the energy system optimization for minimal system costs.

In our 2018 white paper document we described and analyzed the future situation as we see it in 2050. In this paper we also analyzed the implementation of this plan with two focus points: how the energy system should be realized in steps from this point on and secondly where the necessary components, such as electrolysis systems and fuel cells, should be located. We also developed ideas about the roadmap on how to implement the growing renewable energy capacity, which is described in part 5. In part 2 the system setup (what is the 2050 energy demand also compared with the current demands) is explained together with the changes in some energy system parts.

An important conclusion is that our complete substitution of the fossil energy carriers through electrification and hydrogenation results in a substantial low primary energy demand!

- **Low Temperature Heating** only with heat pumps and heat networks using the residual energy from the different system parts.
- **Transport** with only electrical propulsion systems, battery based and hydrogen-fuel cell based, including the shipping sector, inland as well as international
- **Refineries for transport fuels** are not necessary anymore
- **Basic steel making** using hydrogen as the deoxidizing medium
- **Wind- and solar electricity** are 85% of the mix of renewable energy sources.
- **Reliable energy delivery is ensured** due to a well-balanced hydrogen-fuel cell based backup system, supported with a decentralized battery based one day storage systems.
- **The Plastics industry** only uses biomass as the raw input material. Biomass is not used for energy production.

The resulting primary energy demand is 414 TWh in 2050 , much lower compared with other studies! See for instance (Den Ouden 2020,p. 38) figure 7, national control.

Appendix A: Improved High level Block Diagram