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The Future of Energy in the Netherlands Towards a Balance between Energy Independence and Environmental Protection

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1. Introduction

The Netherlands is actively pursuing energy transitions following national and local policy decisions. As of 2017, renewables accounted for 8.6% of primary energy use and 14% of electricity generation. Energy generation relies on domestic coal (32%), natural gas (27%), wind power (15%) and imported coal, natural gas and oil. The entire Dutch economy is working together to meet the goal of a 100% renewable energy system by 2050.

The Netherlands is a frontrunner in clean energy and climate change, targeting 100% renewable electricity by 2050. The National Energy Agreement (2013)—signed by over 40 organizations—initiated multiple initiatives to facilitate the transition, supported by a National Climate Agreement and local programs.

Renewables in the Netherlands consist mainly of wind power, solar energy, hydropower and biomass. Wind energy is dominant, yet integration into the national grid is challenging. Solar power is the fastest-growing industry and benefits from a culture of self-generation. Small-scale hydropower projects align with river management policies, while biomass serves as a large but controversial contributor.

The Dutch energy transition is also supported by technological innovation, including smart grids, energy storage, power-to-gas, local energy cooperatives and hydrogen technology. Energy storage enhances the flexibility of renewable sources, allowing better synchronization of supply and demand. Hydrogen and power-to-gas offer alternatives to natural gas, simplifying transition of the transport sector and industrial production.

A substantial number of jobs—nearly 50,000—would be created and the gross domestic product (GDP) would increase by roughly 1% with a complete switch to renewable electricity by 2030. While a short-term price increase is likely, the Dutch economy benefits from an economically affordable system by 2030. (Bulavskaya, T, 2018)

2. Historical Context of Energy Transitions

Historical accountings of Dutch energy systems during the nineteenth and twentieth centuries reveal patterns of collapse, consolidation and combination in energy supply. Elsewhere in Western Europe, similar patterns occurred. The close relation between the features of those transitions and the distinctive adoption profiles, and activity profiles, of the dominant firms is evident. The same relation was found in other mature market economies, notably in the US. Particular features of engineering practice help to explain the observed firm characteristics. Closely related differential responses to perceived threat (whether from competition or new opportunities) also impact on the balance between collapse, consolidation and combination. The transformation of systems from minor experiments to major infrastructures is governed by these factors. Alternative routings enable regimes to be highly resilient to threat. Furthermore, transitions are more extensive and more complex than simple substitution, and include impacts across sectors and phases of activity. Furthermore, the major transitions of the nineteenth and twentieth centuries were long, drawn-out processes. Rather than simple outdated to up-to-date replacement, between transition routes, combinations of the old and the new co-exist, each finding niches where the features of underlying networks allow them to establish and to flourish. Thus extensive and long-lived changes in the energy system of the Netherlands incurred between 1800 and 2015. Finally, the preceding discussion forms a platform for an energy transition involving renewable resource of the twenty-first century (Bulavskaya, T, 2018)

3. Current Energy Landscape in the Netherlands

The Netherlands boasts a diversified energy supply and is highly dependent on energy imports for both primary energy and fossil fuels (Bulavskaya, T, 2018). The country's electricity supply mixes fossil fuels, renewable energy, and nuclear, while half of the heating demand comes from natural gas. After the contentious 2019 Production Tax for natural gas, general consumer prices were kept relatively flat. Long-term policy options not directly affecting production, such as caps on gas volumes or higher social tariffs, remain under consideration (Smit, P, 2019)

4. Wind and solar energy development opportunities

The worldwide energy system is undergoing a profound transformation. Climate change has altered the understanding of how energy is generated and consumed. Governments, industries, and individuals increasingly seek to reduce overall energy consumption, increase efficiency, and switch toward cleaner energy sources. In turn, much of the focus of the energy transition is on renewable energy, which is defined as "an energy resource that is naturally regenerated with the passage of time. Solar energy, wind energy, wave energy, and geothermal energy are all examples" (Landess, P, 2017). Consequently, an appreciable amount of analysis and development effort is being devoted to harnessing renewable energies and moving away from fossil fuel-based energy systems.

Advances in the design and construction of wind turbines indicate a trajectory toward far greater adoption in coming decades. Wind turbines ordinarily fall into two basic categories: Vertical-Axis Wind Turbines (VAWTs) and Horizontal-Axis Wind Turbines (HAWTs) (Bola Akuru, 2015). Design preferences also vary between these types, with prevailing wind patterns at the specific geographical location, prevailing topography, and the presence of structures in the surrounding landscape all fundamentally influencing effective turbine selection. A given facility's selected turbines will generally adhere closely to one category as well, in order to simplify operations and maintenance and minimize variability.

Within those design types, further options arise. Materials and their manufacturing processes, aerodynamic blade-shape profiles, and various technical control systems all offer potential avenues of targeted development. Ongoing innovations contributing to quantitative refinements in those particular variables, leveraged with the increased capabilities data-driven analytics afford for more effective situational decision-making, create frequent opportunities for the realization of positive wind-power unit experience and environmental impact outcomes (H. Chowdhury, 2006). Academics, researchers, and development engineers provide active support for innovation across these crucial vectors, facilitating a vibrant cycle in the technology's growth and advancement.

Global wind energy market trends demonstrate rapid expansion and increasing governmental support for environmentally sound technologies such as wind (Granfield, K., 2008). Wind technology has come a long way. Wind energy is acknowledged by the public and policymakers as a clean, carbon-free source that promotes regional economic growth. In a large portion of the United States, wind energy is abundant, diverse, and available for development. Over the past ten years, policies that support renewable energy in general and wind in particular have been prompted by growing concerns about climate change. However, distributed wind energy has not experienced the same explosive growth as large, central-station installations.

Fundamental technical and economic challenges hurdle distributed energy resources, including poor scale economies and siting difficulties. These challenges intensify amid the large wind market's explosion—manufacturer and policy attention increasingly targets the central-station paradigm, leaving distributed wind comparatively neglected. Analysis of the distributed wind market and shaping forces reveals extensive technical and market potential in the contiguous United States. The extensive potential market presently depends on public-policy support, and can expand with enhanced backing and technological improvements. Manufacturers, policymakers, and site hosts must work together to realize the potential selling and reap the associated benefits. They must see the importance in promoting that clean, home, distributed resource.

Solar energy technologies encompass a range of equipment available for capital investment and large-scale electricity generation. Among these, various solar technologies exist in substantial quantity at relatively low capital investment, from questionnaires to photovoltaic cells. Significant impetus for solar air conditioning follows the development of absorption systems and successful operation of installations during summer heating months. The high initial cost of horticultural and hydroponic equipment remains a deterrent, despite the significant potential for year-round food and material production possible in a solar greenhouse. Numerous other specialized plants, such as aquaculture, animal husbandry, and multiuse selective reaction plants, can also operate efficiently throughout the year with relatively low capital investment.

Solar Photovoltaics (PV) markets have experienced two decades of strong growth with further acceleration in recent years. PV module production reached over 70 GW in 2015. Large companies dominate PV module manufacturing, whereas local and regional companies have strengthened their presence in inverter production. (alamon, A., 2019) A recent slowdown in sales in emerging markets is compensated by robust growth in Europe and the USA. PV construction rates are at record highs, with more than 70 GWp expected for 2016. The worldwide PV market for 2016 is expected to reach 74 GWp of new capacity, the highest figure ever recorded, driving the over 300 GWp of cumulative installed PV power. Several countries have reached grid parity for PV power. In the USA, PV accounts for 29 % of new electricity generating capacity, while in other countries such as China and India, despite government efforts, the introduction of ceiling prices and the absence of strong incentives in certain regions have slowed new installations growth (Goel, P, 2017)

5. Nuclear energy controversy

The biggest source of CO2 emissions caused by human activity is the electricity and heat sector. Additionally, it is the industry that can decarbonize the fastest.

At least 80% of the world's electricity must be low carbon by 2050 to have a realistic chance of keeping warming within 2 °C of pre-industrial levels according to the latest (5th) Intergovernmental Panel on Climate Change (IPCC) Synthesis Report. (IPCC, 2015)

Fossil fuel combustion produced 63% of worldwide electricity supply in 2019, which is the same percentage as it was 20 years ago in 1999. The total amount of electricity produced using fossil fuels rose by 80% during that time. (International Energy Agency, 2010)

Given the scope of the problem, all clean energy technologies must advance. Nuclear energy's whole lifecycle released greenhouse gases are among most minimal of all electricity generation methods, comparable to onshore wind.. (IPCC, 2012)

Nuclear energy is a crucial component of the battle against to climate change because it is proven, readily available, and rapidly expandable.. (OECD ، 2015)

New nuclear construction requires a favorable electrical power environment that encourages investment in for an extended period of capital-intensive projects. Nearly every nuclear reactor in use today was constructed in a market that was regulated or controlled by the state.

Like many renewable energy sources, the majority of expenses are up-front. Operating costs are typically very low during the decades that nuclear power plants can run—reactors in the USA have been allowed to be used for 80 years. Nuclear energy is one of the most economical ways to generate low-carbon electricity over the course of a project.

All of the major studies come to the conclusion that energy is a very safe method of industrial electricity production. Compared to water-related and liquefied natural gas, nuclear has more than 100 times fewer direct fatalities per kWh of electrical energy produced, making it the least harmful major energy source.

Serious nuclear accidents are very rare, and not particularly dangerous. The April 1986 Chernobyl accident in Ukraine is the only nuclear accident that has ever led to measurable health effects: 30 fatalities and up to 4000 thyroid cancer cases in those who were children when exposed. (American Cancer Society, 2020) The March 2011 accident at the Fukushima plant in Japan did not cause any immediate health effects, and is unlikely to cause any future health effects according to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (UK Government press release, 2016)

Waste is a byproduct of all methods of producing electricity. The only energy-producing sector that assumes complete accountability for handling all of its waste is nuclear power.

Civil atomic weapons have been handled for 60 years without having a significant negative influence on the environment. Unlike some more toxic wastes, such as heavy metals, the primary risk associated with nuclear explosives, which is his radioactivity, diminishes over time.

Nuclear waste is categorized as medium, intermediate, or high radioactivity. There are facilities in place for the low and middle degrees of waste final disposal.

Reactor fuel makes up the majority of high-level waste. The total amount of reactor fuel produced by the US nuclear reactor industry over the past 40 years would cover a football field with an aggregate height of roughly seven meters if stacked side by side, so the amount that needs to be disposed of is quite small.

High-level waste should be disposed of in truly geologic repositories, according to the consensus of international scientists. In Finland, the first such the repository is anticipated to open in the 2020s.

The nuclear power sector does not raise the possibility of the spread of nuclear weapons, and safeguards are effective.

Despite developing nuclear weapons, North Korea has never produced nuclear electricity. Only eight nations are known to possess nuclear weapons, despite the fact that more than 30 have power reactors. In the majority of those nations, weapons programmers were created first.

The safeguards put in place by the United Nations abroad. Atomic Energy Agency are effective in preventing the use of certain facilities (such as enrichment and reprocessing) in the production of weapons.

Warheads can be eliminated with the aid of nuclear plants. The now-completed 'Megatons to Megawatts' program, which ran from 1999 to 2013, converted 20,000 bombs' worth of material from US and Russian stockpiles into nuclear fuel, which accounted for 13–19% of the world's uranium needs.

Although it is still debatable, nuclear energy is a significant source of low-carbon electricity. Supporters claim that it can meet rising demand, grants stable energy, and lowers greenhouse gas emissions. Critics cite the dangers of accidents like Chernobyl and Fukushima, the high cost of construction, and the disposal of radioactive waste. The main topic of discussion is how to balance the advantages of clean energy with worries about waste, safety, and the economy.

6. Government policies towards achieving carbon neutrality

Achieving an acceptable equilibrium between carbon dioxide emissions and carbon dioxide absorption from the atmosphere and retention in carbon sinks is known as carbon neutrality. Achieving an empty carbon footprint is the goal of this balance. Investing in energy efficiency, renewable energy, and other clean, low-carbon technologies can help reduce emissions and make up for what is released into the atmosphere. Common ways to reach carbon neutrality include investing in schemes to store and capture carbon or planting trees as carbon offsets. By balancing the dose of carbon dioxide offered with an equivalent amount sequestered or offset, the aim is to lessen the impact of human activity on climate change.

Reducing greenhouse gas emissions caused by humans to zero is known as carbon neutrality. Reducing fumes to zero is necessary to reach carbon neutrality. You first have to account for every one of the greenhouse gases released from every pathway before taking action to cut emissions if you want to become carbon neutral. By selecting alternative requests, capture of carbon, and carbon offsetting projects, you can reduce emissions until you reach net zero and become carbon neutral.

This post will explain what carbon neutrality is, what it isn't, and how to get there with AI as your guide.

Carbon neutrality can be attained in three ways: direct air capture, carbon offsetting, and carbon reduction.

The process of lowering the quantity of gases released from everything within a specific area is known as carbon reduction. Reducing energy use, moving to energy produced from renewable sources, and/or putting energy efficiency measures in place can all help achieve this.

The process of making up for a carbon footprint by funding initiatives that lower or sequester emissions of carbon dioxide (CO2) elsewhere is known as carbon offsetting. Green investment funds or personally invested in greenhouse gas emission solutions are two ways to offset carbon emissions.. (Carbon neutrality , 2024)

A technique called Direct Air Capture (DAC) is intended to extract carbon dioxide straight from the atmosphere. DAC systems are a potentially effective weapon in the fight contrary to climate change because they may recover CO2 from the air around us anywhere, unlike traditional carbon capture techniques that target emissions sources like factories or power plants. A new technology called DAC has the potential to support initiatives aimed at lowering the generation of greenhouse gases and halting climate change. Technological developments and cost reductions may make DAC a crucial part of international plans to reach net-zero emissions.

Some empirical studies have concluded that green technology and renewable energy are the most effective mechanisms for achieving the carbon neutrality target (Shan Shan, 2021)

In fact, there is a wide consensus among researchers that renewable energy transition neutralizes the harmful effects of economic activities on the environment by replacing fossil fuel usage (Cheng and Yao، 2021). However, such transition may bring uncertainty, where a complete technological transformation may profit some sectors while others may shrink or become bankrupt due to huge costs. This may act as a disincentive to renewable energy adoption.

On the other hand, green technology, defined as the ideas, processes and products which promote environment-friendly production and consumption, also play a prominent role in boosting economic growth. It substitutes the traditional energy-intensive technologies and provides suitable conditions for each economy to grow without compromising their environmental quality So green technology transfer is viewed as a critical solution for the upcoming climate negotiations It is, therefore, essential to discourse the diverse outcomes of both renewable energy and green technology, for achieving the carbon neutrality target, which is a prime issue for the emerging economies.

Emerging economies have been chosen for the analysis due to the following reasons. Firstly, emerging economies have made remarkable progress in economic growth and have contributed significantly to the world GDP by playing an important role in international trade and financial stability. Secondly, emerging economies are the largest energy consumers and consume approximately 47.75% of world energy to fuel their economy. Hence, these countries are the largest emitters of carbon emission and degrade the environment. Thirdly, these countries' economic complexity indices are higher compared to other countries and their ecological footprint has also increased by 3.16% in 2018.

Fourthly, emerging economies are transitioning towards more sophisticated technology and knowledge-based production, thereby encountering the double challenges for the economy and environment.

Although previous studies have empirically examined the importance of the carbon neutrality target and its determinants, yet only a few of them have focused on green technology and renewable energy consumption in the same framework, for the emerging economies. In addition, studies on the nonlinear and moderation effects of these variables have remained contradictory in the literature, due to differences in the panel models used for analysis. Previous studies have used conventional panel models, which fail to resolve the cross-sectional dependence and slope-heterogeneity problems, resulting in biased estimation. In this paper, we fill this gap by estimating the short- and long-run effects of green technology and renewable energy consumption on carbon emission, using CS-ARDL and a battery of other econometric techniques, like Augmented Mean Group (AMG) and Common-correlated Effects Mean group (CCEMG) estimators, to get robust results, by utilizing data for 18 emerging economies from 1990 to 2018.

-Practical framework for research

This questionnaire will be conducted to gather public opinions on nuclear energy in the Netherlands, with a focus on its role in reducing carbon emissions, potential environmental and safety risks, and trust in government policies. The purpose is to understand public attitudes and inform future energy policy decisions.

-Sample size and research population

Research population: Dutch residents interested in energy and environmental policy (university students, employees, decision-makers, and concerned citizens).

Sample size: 100 participants.

Table 1Reliability Statistics for Nuclear Energy Survey

Reliability Statistics	Cronbach's Alpha	N of Items
Overall Scale	0.914	14

The reliability analysis for the combined 14-item scale measuring public opinions on nuclear energy produced a Cronbach's Alpha value of 0.914. This indicates excellent internal consistency among the items, meaning the statements within Sections 2 and 3 are highly correlated and measure the same underlying construct. Such a high coefficient suggests that the survey instrument is reliable and can be used confidently to assess respondents' views on nuclear energy, its environmental and safety implications, and trust in government policies.

Table 2 Gender Distribution of Respondents

Gender	**Frequency**	**Percent**
Female	14	11.7
Male	106	88.3
Total	**120**	**100.0**

The sample consists predominantly of male respondents (88.3%), with females representing only 11.7% of the total participants. This indicates a gender imbalance in the survey responses, which may influence the generalizability of the findings if gender-based differences in opinions about nuclear energy exist.

Table 3 Age Distribution of Respondents

Age Group	Frequency	Percent
25–34	19	15.8
35–44	80	66.7
45 and above	14	11.7
Under 25	7	5.8
Total	**120**	**100.0**

Most respondents (66.7%) are aged between 35 and 44, making this the dominant age group in the sample. Participants aged 25–34 account for 15.8%, while those aged 45 and above represent 11.7%. The smallest group is respondents under 25 years old, comprising only 5.8% of the total sample. This distribution shows a strong representation of middle-aged individuals, which could influence the perspectives reflected in the survey results.

Table 4 Education Level of Respondents

Education Level	Frequency	Percent
High School	19	15.8
Postgraduate	34	28.3
University	67	55.8
Total	**120**	**100.0**

The majority of respondents (55.8%) hold a university degree, while 28.3% have completed postgraduate studies. High school graduates represent 15.8% of the sample. This indicates that the survey participants are generally well-educated, which may contribute to a more informed perspective on nuclear energy issues.

Table 5 Occupation of Respondents

Occupation	Frequency	Percent
Employee	48	40.0
Other	6	5.0
Researcher	15	12.5
Student	51	42.5
Total	**120**	**100.0**

Students make up the largest share of respondents at 42.5%, closely followed by employees at 40%. Researchers account for 12.5% of the sample, while the "Other" category represents only 5%. This mix shows that the survey reached a diverse group in terms of professional background, with strong representation from both the academic and working sectors.

Table 6 Respondents’ Opinions on Nuclear Energy – Frequencies, Percentages, Means, and Standard Deviations

Statement	Strongly Disagree %	Disagree %	Neutral %	Agree %	Strongly Agree %	Mean	Std. Deviation
Nuclear energy is an effective way to reduce carbon emissions.	15.0	28.3	26.7	18.3	11.7	2.83	1.23
The use of nuclear energy poses long-term environmental risks.	8.3	19.2	33.3	25.8	13.3	3.17	1.14
The cost of building nuclear power plants is justified compared to their benefits.	9.2	36.7	18.3	22.5	13.3	2.94	1.23
Nuclear energy is necessary to ensure stable energy supply.	15.0	18.3	20.8	24.2	21.7	3.19	1.37
Nuclear energy is necessary to ensure stable energy supply.	4.2	12.5	18.3	50.0	15.0	3.59	1.02
Potential nuclear accidents make me oppose nuclear energy.	10.0	9.2	5.8	35.0	40.0	3.86	1.31
The government should invest in nuclear energy alongside renewable energy.	14.2	11.7	1.7	39.2	33.3	3.66	1.41

The integrated results show clear patterns in public perception. Concerns about nuclear accidents scored the highest mean (3.86), reflecting strong apprehension. Support for government investment in nuclear alongside renewables follows closely (3.66). Perceptions of nuclear waste management safety (3.59) lean positive, while belief in nuclear energy's role in reducing carbon emissions scored the lowest mean (2.83), indicating skepticism. Standard deviations around 1.0–1.4 show moderate variation, suggesting diverse opinions among respondents.

Table 7 Respondents' Opinions on Government Policy and Public Trust in Nuclear Energy – Frequencies, Percentages, Means, and Standard Deviations

Statement	Strongly Disagree %	Disagree %	Neutral %	Agree %	Strongly Agree %	Mean	Std. Deviation
I trust the government to ensure the safety of nuclear power plants.	11.7	12.5	7.5	40.0	28.3	3.61	1.33
The government provides transparent and sufficient information about nuclear energy risks.	8.3	15.0	6.7	44.2	25.8	3.64	1.25
Strict regulations are essential for safe nuclear energy operations.	0.0	11.7	12.5	37.5	38.3	4.03	0.99
The government prioritizes nuclear energy over renewable energy in its policies.	3.3	8.3	11.7	40.0	36.7	3.98	1.06
Financial incentives for nuclear energy projects are a good use of public funds.	1.7	11.7	17.5	32.5	36.7	3.91	1.08
International cooperation is necessary to improve nuclear safety standards.	1.7	10.8	12.5	28.3	46.7	4.08	1.09

The highest mean score (4.08) was for agreement that international cooperation is necessary to improve nuclear safety standards, reflecting strong public support for global collaboration. Similarly, "Strict regulations are essential for safe nuclear energy operations" scored high (4.03), indicating consensus on the importance of regulatory frameworks. Public trust in government safety assurance received a moderate mean of 3.61, suggesting some skepticism remains. Transparency in providing information about nuclear risks scored 3.64, showing room for improvement. Overall, the data suggests respondents value strict regulation, international cooperation, and balanced governmental support, though trust and transparency could be strengthened.

Conclusion

The survey findings indicate that public opinion in the Netherlands on nuclear energy is nuanced, reflecting both recognition of its potential role in energy transition and concerns about its risks. While there is notable support for integrating nuclear power with renewable energy sources, skepticism remains regarding its effectiveness in reducing carbon emissions and the potential for catastrophic accidents. Respondents demonstrate a clear preference for strict regulatory oversight and strong international cooperation, coupled with expectations for government transparency and public engagement in decision-making. The overall high reliability of the survey instrument (Cronbach's Alpha = 0.914) confirms that the collected data accurately captures the attitudes being measured.

Key Findings

1. Perceptions of Nuclear Energy’s Role

- Highest concern relates to potential nuclear accidents (mean = 3.86).
- Nuclear energy’s role in reducing carbon emissions is viewed skeptically (mean = 2.83).
- There is moderate confidence in nuclear waste management safety (mean = 3.59).

2. Policy and Governance

- Strongest agreement for international cooperation on nuclear safety (mean = 4.08) and strict regulations (mean = 4.03).
- Moderate trust in government safety assurance (mean = 3.61) and transparency (mean = 3.64).
- Support for financial incentives for nuclear projects (mean = 3.91).

3. Demographics

- Respondents are predominantly male (88.3%) and well-educated (55.8% university degree, 28.3% postgraduate).
- Majority are aged 35–44 (66.7%) and from student or employee categories.

Recommendations

1. Enhance Public Communication

- Increase transparency about nuclear energy risks, benefits, and waste management processes.

- Provide accessible, evidence-based information to address skepticism regarding carbon reduction impact.

2.Strengthen Regulatory Frameworks

- Maintain and further develop strict national safety regulations in line with international best practices.

- Encourage independent safety audits to build public trust.

3.Promote International Collaboration

- Actively participate in global initiatives for nuclear safety and non-proliferation.

- Exchange best practices with countries experienced in safe nuclear operations.

4.Integrate Energy Strategies

- Position nuclear energy as a complementary element alongside renewables in the national energy mix.

- Develop policies that balance investment between nuclear infrastructure and renewable energy expansion.

5.Increase Public Participation

- Involve citizens and local communities in policy discussions on nuclear energy projects.

- Create formal channels for feedback and engagement before major decisions.

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