Sustainable Energy Supply in Rural Arctic Areas

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Abstract:

The focuses on which energy resources are available in the Arctic and how the various resources can be harvested with different mature energy technology options for remote Arctic communities. Mature energy generation technology means that the operation under harsh and cold climatical conditions is well proven. Furthermore, the current energy situation among remote Arctic communities will be mapped out, with an analysis of which energy sources are used, the share of the different sources, and the energy demand of remote communities. After explaining the different energy generation options and main drivers for using renewable energy in remote Arctic communities, three case studies have been conducted. The case studies examine the viability of a potential energy transition for Arctic communities. The case studies also share some insights from field visits in remote communities on generating electricity with renewables and potential energy saving potentials. The last part elaborates on different integration strategies for renewable energy options. The focus lies on how to finance the energy transition in remote Arctic communities, which can help to structure the energy transition process financially. The dissertation finishes with an overall conclusion on the importance of renewable energy for Arctic communities. The research shows that renewable energy can be vital for remote communities to become more energy independent and lower the energy cost burden.

Background:

One of the most severe socioeconomic impacts related to the use of diesel is its transportation. The harsh Arctic climate conditions make the shipment risky. In general, two options can be found using trucks and ice-roads – frozen rivers, if the ice layer is stable enough - the second option is to ship the fuel on barges if the rivers are navigable or the community is at the shore. For both options, it is difficult to schedule a shipment within the short timeframe available. Especially the ice-roads become more unstable due to climate change [7]. That leads to a higher risk of transportation accidents [8].

Another problem is that if not all the fuel for the next year can be delivered during the short timeframe, it has to be flown to the communities, which is extremely expensive. All of these factors lead to high transportation costs. The transportation cost is one part of the high electricity cost. Other reasons for the high electricity price are the large storage needed and the remoteness, which makes every inspection and spare part delivery expensive. Reliability is vital in the Arctic since electricity is essential for health and well-being under harsh climate conditions [9]. The noise of the diesel generators can be a disturbing factor in remote and quiet communities.

The environmental impact of diesel use is mainly related to greenhouse gas emissions, like CO2 and black carbon [10,11]. Both are a significant component of climate change, but black carbon has a unique role in the Arctic. After its lifetime as an aerosol, if the particular matter settles down on ice or snow [12], the small particles absorb solar radiation, and that 22 increases the meltdown of snow and ice. Another impact is more related to transportation and storage. Sometimes accidents happen during the transport, or storage leaks can result in diesel spills [13,14]. These diesel spills can lead to land degradation, which can be traced even several years after the impact. Furthermore, toxins from the diesel spill can enter the food chain [6].

As well as the environmental impact related to the use of diesel, remote Arctic communities are facing a major issue resolution from power generation with diesel. The already described complex transportation of diesel to remote places comes along with high fuel costs [7]. Using expensive diesel for electricity generation results in high electricity production costs [8]. As long as no subsidies for diesel powered electricity generation or electricity are in place, the consumer has to pay high electricity prices. The increased electricity prices occur in a region where unemployment and poverty are common [15]. This cost burden for inhabitants of remote Arctic communities is a significant reason for conducting the following research. The subsequent analysis will determine whether renewables can help overcome the cost burden.

Problem:

This study includes 553 remote communities in the Arctic and sub-Arctic areas of Alaska, Canada, Greenland, and Norway. All communities included in this study are identified in the literature review through databases provided by corresponding utility companies, energy authorities, and scientific reports. Fig. 1 shows the location of communities across the study regions (Arctic Norway, Greenland, Canada and Alaska).

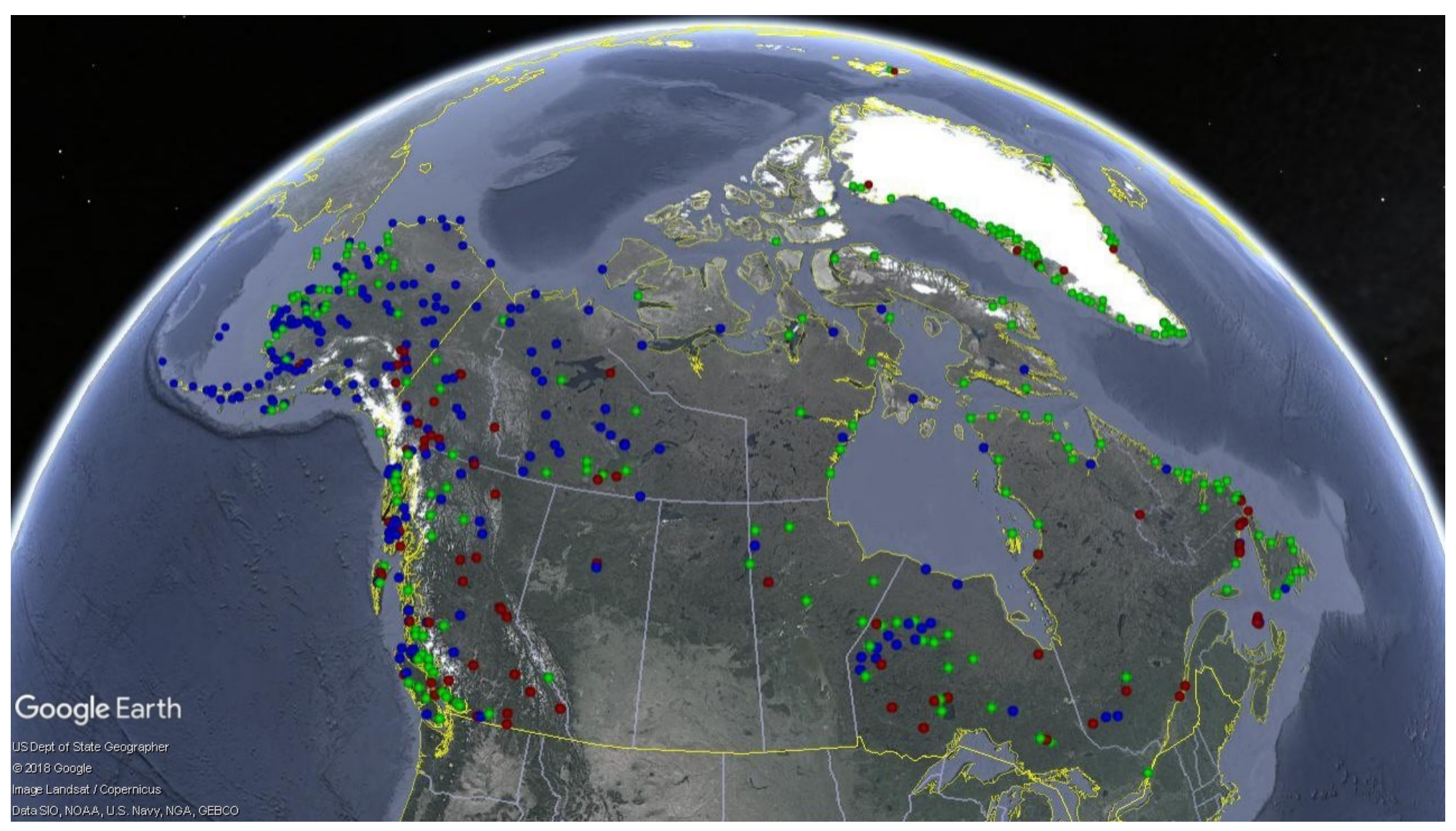

Figure 1. Illustration of the research area according to detailed data (green), basic data (blue), and identified data (red) [29].

Up to 79% of Arctic communities included in this study were, at the time of this study exclusively dependent on diesel as a primary energy source, with 6% of communities using 33 hydropower systems, and 15% using hybrid systems for their energy (see Fig. 2). Hybrid systems are those systems that use fossil fuels mixed with renewables [13].

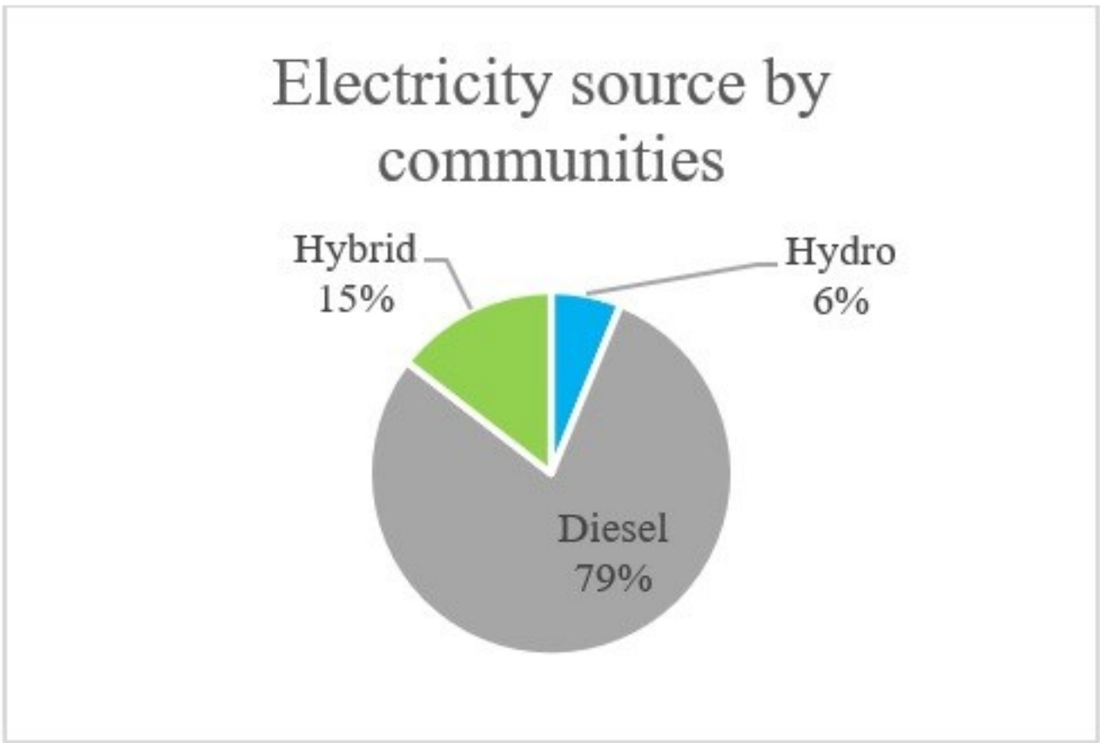

Figure 2. Shows the energy sources for generation of electricity such as diesel, hydropower, or hybrid systems, which are a combination of a diesel generators with non-dispatchable energy resources such as wind and PV power referring to the number of communities. Data used: Basic Data & Detailed Data (gathered by author).

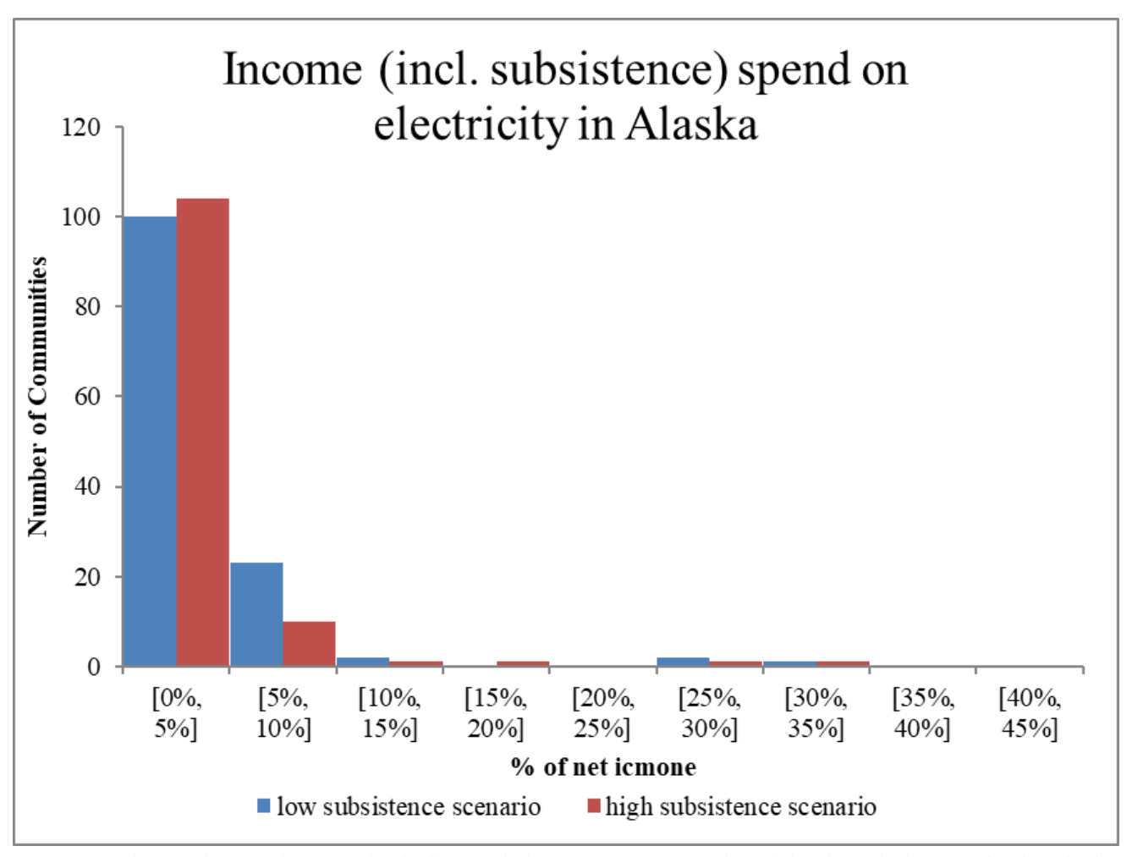

Figure 3. shows the net income including subsistence spent on electricity in relation to the local electricity consumption (low subsistence scenario net income + 1,200 US$ for indigenous, high subsistence scenario net income + 3,600 US$ for indigenous)

The different lifestyles of indigenous and non-indigenous communities may, however, affect the electricity consumption. Among indigenous communities, where subsistence is customary and makes up an important part of material wellbeing of households, the demand for electricity may be lower. We therefore attempt to account for this effect as well and the collected data on electricity sales for residential purpose. Figure 3 represents the burden of electricity costs in the case of a mixed economy setting. Therefore, two scenarios have been established: a low subsistence scenario, which adds 1,200 US$ to the income per capita in indigenous communities; and a case of high subsistence, which adds 3,600 US$ to the indigenous income per capita. The origin of the values is explained earlier in this section. Results for the Canadian Arctic can be expected to be similar to the US Arctic, since the lifestyle is similar and both regions have high rates of poverty and unemployment.

More Information:

24. February 2023 08:30-10:00 & 10:30-12:30
Arctic Urban Sustainability in Transit ID: 33
Presentation: Sustainable Energy in Remote Arctic Communities
Room: Hörsaal 3

Methodology

System dynamics (SD) is the method used in this study. SD is a method that analyzes complex processes or problems using a model of the real-world situation. The model, which is an abstract simplification of the real world rather than an exact representation [13], should mimic the behavior of real-world decision-makers [14], and it is essential to identify the optimal ratio between abstraction and detail in the modeling process. SD's particular strength in the context of this study is that it is a powerful tool for analyzing complex systems for which real experiments can be difficult and costly [15]. It is often used in project and change management to analyze the impact of delays and interruptions, which may be expected in the renewable energy integration process. Advance knowledge of and preparation for delays and interruptions can ensure a more stable energy transition process and minimize rework and adjustments [16]. The SD method involves the creation of a structural model of the situation with an integrated feedback function backed up by a "cause and-effect relationship within the system" [16]. This feedback function can help facilitate a 78 more detailed analysis of the decision-making process [17]. The feedback can represent, for example, non-linear interactions between elements in the system, management decisions, or performance measurements, as are anticipated in the policy aspect of this study [18]. Feedback is crucial for large-scale projects such as the energy transition, for which the performance of more traditional models and methods, such as Gantt, PERT, and critical path, is limited. SD can take feedback effects into account to facilitate problem-solving [19]. More specifically, SD examines the impact of feedback between different elements within a complex system. The feedback need not follow a linear relationship, which is often crucial for the detailed analysis of management and policy actions [18] [17]. Non-linear feedback is expected to be highly significant in the evaluation of different policy strategies for energy transition pathways. The transition of energy systems such as that under consideration in this study will likely encounter various feedback loops and non-linear behaviors throughout the transition process. Another key strength of SD is that the results are easily communicated. A causal loop diagram (CLD) may be used to communicate results to individuals who are not trained in SD because it is a highly intuitive representation of the situation [13]. Therefore, we believe that SD has significant potential for analysis of the transition process in remote Arctic communities. SD has not been used hitherto to analyze transition processes of islanded microgrids. Nevertheless, it has exhibited exceptional potential for other transition processes [20] [21] [22] [23] [24] [25] and has also been employed in more holistic energy transition studies [26].

Results:

In this section, the differences between the various scenarios and the cases' structure are explained. The base scenario and the three policy scenarios presented in Table 1 were designed to analyze the different integration strategies and environments in which renewable energy might be implemented. As Table 2 indicates, a set of four cases were created for each scenario to analyze the different strategies available for integrating renewable energy into the energy mix.

Table 1. The scenarios show the different integration strategies which use different financial tools to stimulate the energy transition.

	RE penetration	CO_2 tax	External funding
Base Scenario	no	no	no
Scenario 1	yes	yes	no
Scenario 2	yes	yes	yes
Scenario 3	yes	no	no

Table 2. The structures of the different cases used for evaluating each scenario. The starting point can vary; early means a direct start, and late means the energy transition starts at a later time. The starting point is the result of initial public pressure. Speed denotes relatively how swiftly the renewables are integrated, which depends on the inhabitants' sensitivity.

	Start	Speed
Case 1	late	slow
Case 2	late	fast
Case 3	early	slow
Case 4	early	fast

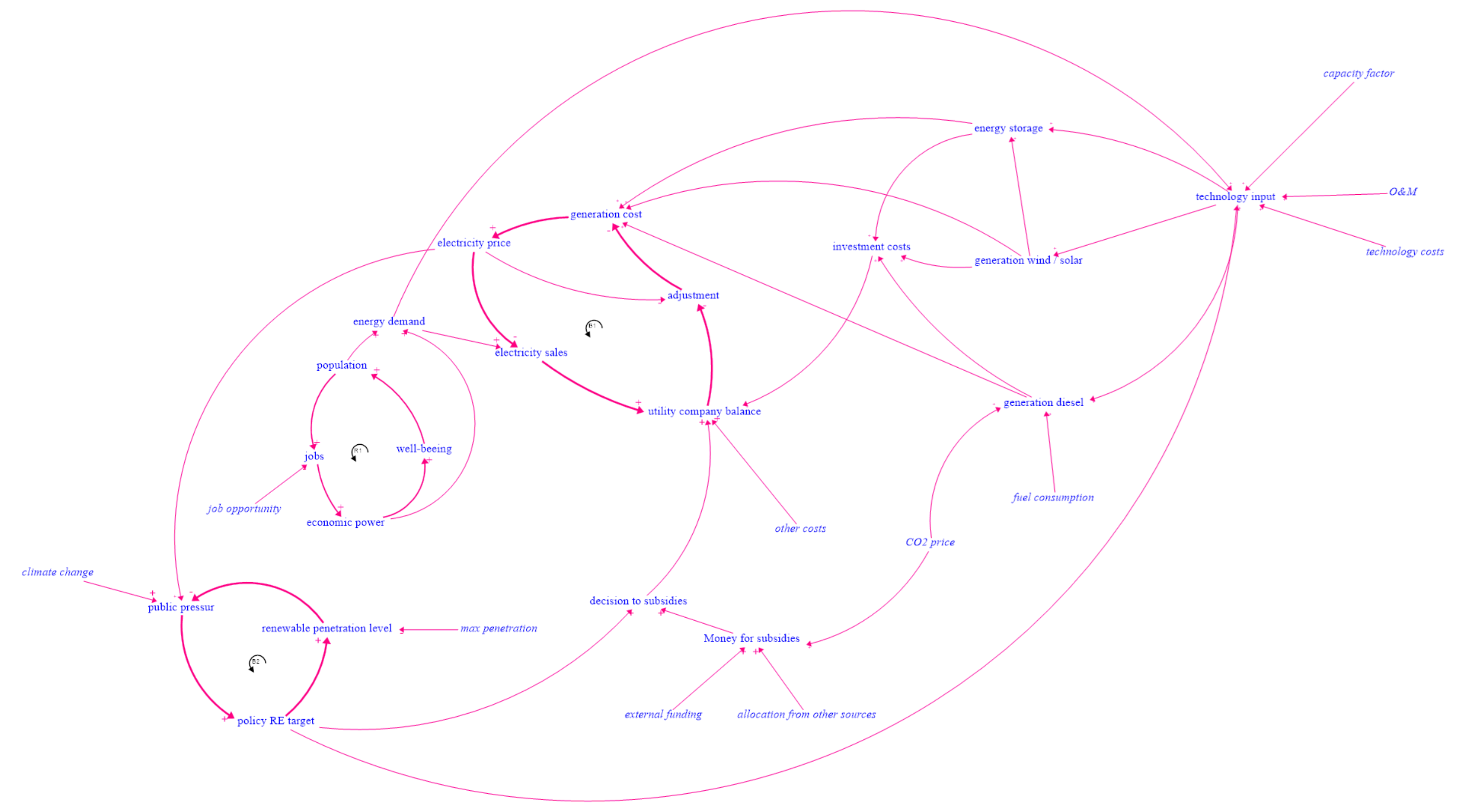

Figure 4. The causal loop diagram represents the interaction between the key variables in the energy transition model . The model has three mail loops. Loop R1 represents the economic part which leads to changes in energy demand. Loop B1 is responsible for the energy price adjustments in accordance to the energy generation costs. Loop B2 represents the energy policy interventions.

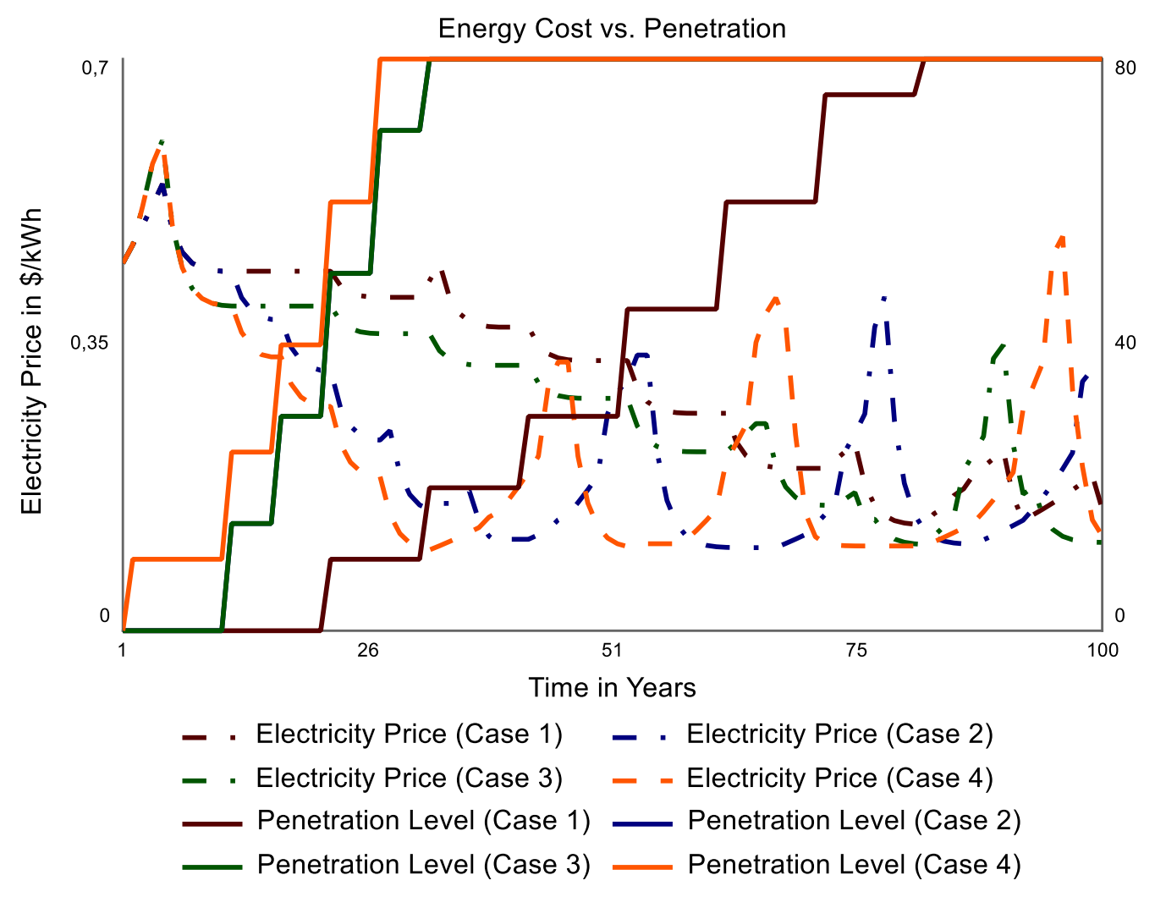

Figure 5. Energy costs vs. renewable penetration levels. The penetration level results from public pressure and policy, and the electricity price is the result. The solid lines represent the renewables' penetration level, and the dashed lines represent the electricity costs.

Table 3. Average electricity prices of all cases over a period of 50 years (Diesel in the business as the usual case has an average electricity price of 0,47$/kWh)

Average Electricity Price 50 Years

	Case 4	Case 3	Case 2	Case 1
Scenario 1: CO2 tax	0.26	0.38	0.28	0.41
Scenario 2: CO2 tax and external funding	0.27	0.38	0.28	0.41
Scenario 3: no support	0.29	0.38	0.29	0.42

As assumed in the dynamic hypothesis the system is trapped in a path dependency and a degree of force is required to break through that dependence. In all four scenarios, a worse-before-better behavior is evident from the end consumer's perspective within the first ten years. The electricity price rises, creating the momentum required to initiate the transition process. This makes the financial situation worse for the end consumer. Following the transition, the electricity price falls to below the initial level, thus improving the situation from the consumer's perspective. As the share of renewables increases, electricity prices become increasingly independent of the impact exerted by fuel price changes. Table 3 offers a closer look at the different scenarios and associated cases' electricity prices. The results reveal a significant range in the average electricity prices across the simulated time, with costs ranging from 0.26$ per kWh to 0.42$ per kWh across all cases from scenarios 1, 2, and 3. Overall, the highest average electricity price for renewables is 0.05$ lower per kWh than the average electricity price at 100% diesel. Comparison of Table 4 with the 100% diesel case (see base scenario business as usual) reveals a significant cost saving. The average cost of generating electricity with 100% diesel would be 0.47$ per kWh, which includes the anticipated changes in diesel costs and CO_2 tax.

Conclusion:

In conclusion, this study confirms the cost-saving potential that other studies have indicated for Arctic case studies as a result of using renewable energy. However, a major novelty of this study is its demonstration of the pathways via which energy transition can be realized and financed. The key message is the importance of shifting from diesel to a more sustainable energy mix from both the economic and environmental perspectives. The simulation performed indicates that a hybrid energy system can reduce electricity prices more efficiently than an entirely diesel-based scenario, which may reduce the cost burden. Furthermore, the work has demonstrated that it is essential to structure the energy transition well. A well-structured energy transition process will make it possible to conduct the energy transition in a way that is more financially feasible.