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# Modelling and development of sustainable energy systems

**Muhammad Amir Raza[1,2,*], M. M. Aman[2,3], Abdul Ghani Abro[2,3], Muhammad Shahid[4], Darakhshan Ara[5], Tufail Ahmed Waseer[6], Mohsin Ali Tunio[1], Shakir Ali Soomro[1], Nadeem Ahmed Tunio[1], and Raza Haider[7]**

[1] Department of Electrical Engineering, Mehran University of Engineering and Technology, SZAB Campus Khairpur Mir's, 66020, Pakistan
[2] Centre for Advanced Studies in Renewable Energy (ASURE), NED University of Engineering and Technology, Karachi, 75270, Pakistan
[3] Department of Electrical Engineering, NED University of Engineering and Technology, Karachi, 75270, Pakistan
[4] Department of Electronic Engineering, Dawood University of Engineering and Technology, Karachi, 74800, Pakistan
[5] Department of Information Sciences and Humanities, Dawood University of Engineering and Technology, Karachi, 74800, Pakistan
[6] Department of Electronic Engineering, Mehran University of Engineering and Technology, Jamshoro, 76062, Pakistan
[7] Department of Electrical Engineering, Balochistan University of Engineering and Technology, Khuzdar, 98100, Pakistan

* **Correspondence:** Email: amirraza@muetkhp.edu.pk; Tel: +923003142647.

**Abstract:** Due to the recent climate change, organizations all over the globe are developing plans for reducing carbon emissions by developing clean energy technologies and energy efficient devices. However, the path for transition to green energy system is still unclear and in general, the representation of green energy supply for transition pathways is limited. Therefore, this study outlines a plan for getting Swedish energy sector completely carbon neutral by 2050. The approach can also be applicable to the majority of nations worldwide. Computer based simulations are performed on Energy PLAN software for making clean, green and sustainable energy system that can balance every component of entire energy system during the study period 2022 to 2050. This study takes into account the sustainable use of renewable sources for all economic sectors as well as the interchange of energy with nearby nations under the two scenarios. Additionally, the energy system

works in tandem with other industries to create a fully carbon-free environment. The results revealed that, 50% de-carbonization is possible till 2035 and 100% de-carbonization is possible till 2050. This enables a discussion of how ambitious 10-year goals might serve as a first step toward the mid-century elimination of fossil fuels from the energy sector.

**Keywords:** energy model; energy transition; clean environment; green economy; energy balance; energy mix

## 1. Introduction

In order to achieve the Paris Agreement's target of keeping the average global temperature increase to 1.5 ℃ for sustainable development is a difficult task for international energy leaders [1]. The International Energy Agency (The International Energy Agency is a Paris-based autonomous intergovernmental organization, established in 1974, that provides policy recommendations, analysis and data on the entire global energy) noted that achieving net-zero global carbon dioxide ($CO_2$) emissions by 2050 through some sustainable initiatives [2]. Currently, energy and transportation sectors are producing three quarters of today's $CO_2$ emissions. As such, strategy should be developed on these sectors for achieving de-carbonization. Alongside, some efforts for lowering $CO_2$ emissions in other sectors are also necessary in coordination with the energy and transportation sectors [3]. This coordinated action necessitates an integrated strategy that takes into account all sectors which are responsible for producing $CO_2$ emissions. Furthermore, no nation or region can actively help to achieve the global objectives alone [4]. In order to effectively address issues like the global use of renewable resources, de-carbonization of aviation and shipping, and also international exchange of electricity [5]. So, the various nations include developed or developing would also need to coordinate their efforts.

Earlier all studies were focused on de-carbonization of energy sector with a lower degree of inclusion for the heating, transportation, and industrial sectors [6] but this study covers all the sectors includes industrial, commercial, residential, transportation and agriculture for making clean, green and sustainable energy system. Some developed countries have made efforts for achieving 100% renewable energy system (RES) at national level includes Germany, Finland, Ice Land, Norway, Paraguay, Austria, Brazil, Costa Rica, the Philippines, and Kazakhstan [7]. Some countries have been proposed at the regional level include Aalborg Italy, South East Europe, Bolzano Denmark, Akita Japan, and the Åland Islands [8]. The detailed description of studies on clean, green and sustainable energy system are given in Table 1. Ultimately, this demonstrates a tendency toward a still better and more appropriate understanding of the effects of a fully clean, green and sustainable energy system powered entirely by renewable energy [9]. These assessments must be taken at global context, which should take into account the availability and sustainable use of renewable sources [10]. Ratanakuakangwan S et al. [11] address this issue at the European level in their scenario that by prioritizing the usage of renewable sources at significant level in critical sectors can help in making the 100% RES at lower cost and also at balance energy mix. At the national level, some developed and underdeveloped countries, have shown that 100% RES are possible by energy savings and also by utilization of renewable resources [12]. However, when approaching technological limits of renewable power plant or taking into account their use to meet non-energy demands, and also

increasing utilization rates of some energy sources, like hydro, tidal, wave, biomass, solar and wind might raise some issues [13]. Jäger-Waldau A et al. [14] estimated that, needs of energy for transport sector must be fulfilled by incorporating the renewable resources at local level. In this paper complete transport sector includes shipping, aviation, and other transport services are supplied energy through the renewable resources. Such a strategic plan might be implemented or scaled up to the national level, and coordinated on a transnational or worldwide scale for developing clean, green and sustainable energy system.

**Table 1.** Studies on clean, green and sustainable energy system as on 2022.

| S. No | Country | Model | Purpose |
|---|---|---|---|
| 1 | Spain [17] | MARKAL | Explored renewable energy technologies for economic development |
| 2 | Syria [18] | MESSAGE | Renewable energy-based power supply options were evaluated |
| 3 | France [19] | MARKAL | Identified relationship between energy efficiency and demand |
| 4 | China [20] | MESSAGE | Environment assessment for future sustainability |
| 5 | Finland [21] | Energy PLAN | Delivered renewable power to all economic sectors |
| 6 | South Korea [22] | LEAP | Developed strategy for clean energy system |
| 7 | Pakistan [23] | Energy PLAN | Future sustainable energy pathways were identified |
| 8 | Azerbaijan [24] | LEAP | Identify the negative consequence of climate change |
| 9 | Nepal [25] | Energy PLAN | Exploring possibilities of renewable power to overcome energy crises |
| 10 | Basque [26] | MARKAL | Analyzing pathways for clean and green energy system |
| 11 | Asia [27] | MESSAGE | Forecasting carbon emissions of energy |
| 12 | Indonesia [28] | LEAP | Facilitate renewable production and reducing carbon emissions |
| 13 | Baltic Countries [29] | MARKAL | Clean renewable energy technologies were assessed |
| 14 | Europe [30] | Energy PLAN | Efforts were made on making carbon free Europe |
| 15 | India [31] | MESSAGE | Identified relationship between energy efficiency and power generation |
| 16 | North Macedonia [32] | LEAP | Focus on making green environment by exploring renewable sources |
| 17 | Pakistan<br>This Study | LEAP | Utilizing the maximum share of renewables for supplying green power to all the electricity consuming sectors such as industrial, commercial, domestic, and transportation. |

Despite several attempts have been made in making clean, green and sustainable energy system, there is still a research gap in the creation of consistent and coherent plans for appropriate design of completely decarbonized energy system at the national level while taking the global context into account [15]. In this article, a detailed strategy at national level for how to decarbonize the energy sector is presented and calculated. This is done while taking into account the requirement for international coordination with other $CO_2$ emitters sectors, as well as regional coordination with the rest of Europe, and ultimately global coordination [16]. So, this study presented an idea on how to make clean, green and sustainable energy system by paying close attention to renewable routes. This study focuses on the fundamental and general principles for developing a plan for a nation to achieve a completely clean, green and sustainable energy system at lower cost and also at balance energy mix. We used the case of Sweden by the year 2050 to illustrate this broad principle. In the course of the political process, several ideas and plans from various parties of stakeholders have been presented and considered for identifying the best way to carry out the political objectives. In this paper, one of these ideas, which symbolizes the concept of clean, green and sustainable energy system in Sweden

by 2050 is described. This study's goal was to demonstrate how a 100% carbon-free civilization may be achieved by the year 2050.

The study presents an intriguing instance since it assumes that by 2035, the energy, industrial, and transportation sectors would have undergone a major change. In order to accomplish the short-term objective in the coming decade, the article analyses and outlines a plan, and it also uses the scenario for the years 2035 and 2050 for as an offset to achieve clean, green and sustainable energy system at lower cost and also at balance energy mix in Sweden by 2050. This enables a discussion of how ambitious 10-year goals might serve as a first step toward the mid-century elimination of fossil fuels.

## 2. Material and methods

Another step is taken in a long history of presenting technological ideas for the transition to renewable energy system and the climate discussion in the development of clean, green and sustainable energy system by 2050. The flow diagram of this research is given in Figure 1, which is designed on Energy PLAN software [33]. Alongside, to design clean, green and sustainable energy system, specialists from many technical fields were also engaged in a back-and-forth discussion while an energy systems model analyses how different technologies fit into a larger picture.

It was emphasized that Sweden would need to decide whether to rely primarily on fossil fuels, which are costly, or on 100% renewable resources, which are less costly. Secondly, Sweden would need to achieve its goals for greater renewable energy following Denmark and reducing $CO_2$ in a way that would reasonably allow the rest of Europe and the rest of the globe to accomplish the same [34]. The latest study continues to concentrate on this specific task for creating balance renewable energy mix in lower cost. A nation may totally decarbonize or switch to 100% RES in a variety of methods with balance renewable energy mix. Finding practical, workable, and cheap techniques is the goal of investigations. This study have demonstrated that in order to properly transition to a renewable society, the following requirements or guiding principles must be met include Sweden shouldn't use more fossil fuels than its fair share of the global market, facilitate a greater integration of intermittent RES, namely biomass, solar and wind, into the electricity supply because Sweden should provide its flexibility and reserve capacity and Sweden should achieve its goal of a 50% $CO_2$ reduction in 2030 in a way that would be compatible with a society that is completely decarbonized by 2050. In 2021, Sweden produces 32.14 million metric tons of $CO_2$ emissions. This amount of $CO_2$ emissions would become negligible in the year 2050 [35].

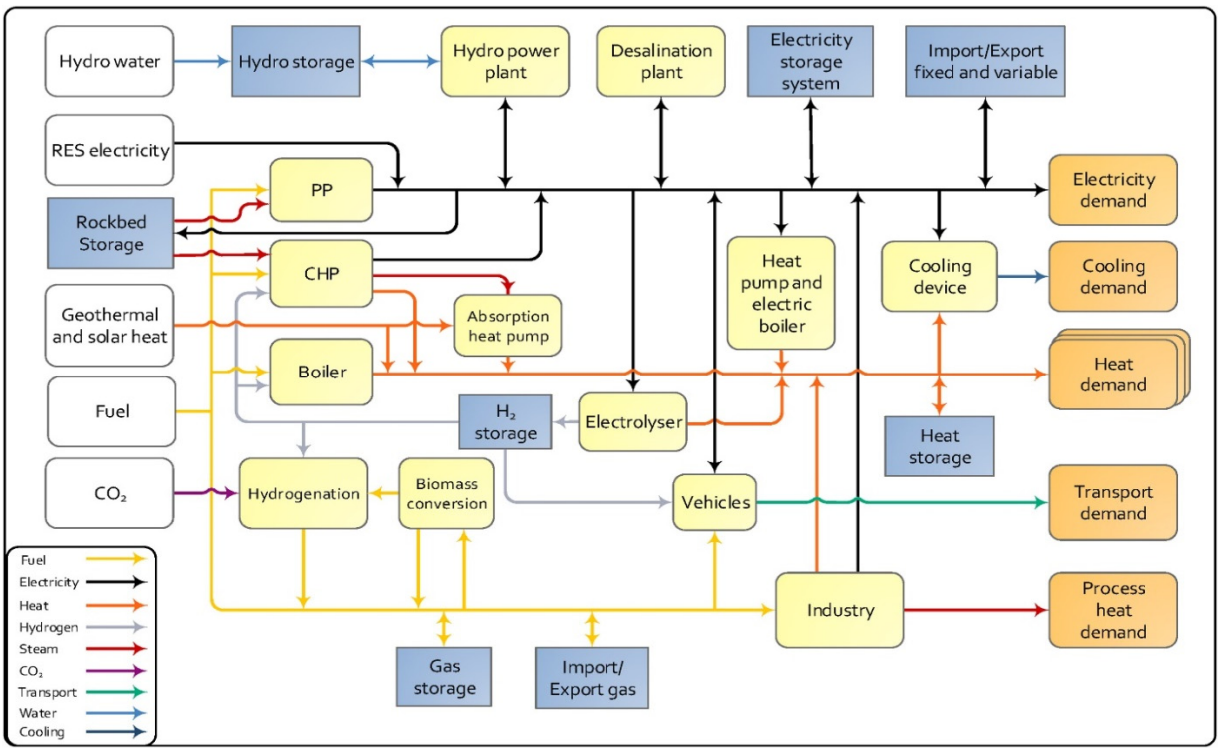


**Figure 1.** Research flow diagram of clean, green and sustainable energy system.

Of course, the question is what may cause Swedish society to progress in this path. A clean, green and sustainable energy system would be a workable and economical option [36]. The purpose of this perception is to offer the technical underpinnings for a paradigm shift away from narrow-minded thinking and toward a cogent and comprehensive understanding. The main focus is on developing and identifying the most feasible and cost-effective techniques to put into practice for upcoming fully decarbonized energy systems, which were initially announced in 2012. After being pre-released in a brochure from 2013, the definition of the clean, green and sustainable energy system was published 2014 [37].

Identifying possible synergies between sub-sectors is the central concept of the clean, green and sustainable energy system method [38]. The idea is that by merging the sub-sectors and leveraging networks for heating, cooling, and gas in addition to electricity, the most practical and affordable solutions may be developed. Clean, green and sustainable energy system highlights the necessity of integrating renewable sources with grids and goes beyond for integration of all sub-sectors [39]. The strategy takes into account more than only electricity to fuel, gas and heat, for example, e-fuels in the district heating grid and also by employing extra heat produced by industry.

Create a simulation based environment in which power plant technologies and industries are analyzed thoroughly by proper and in-depth analysis and it is also necessary to identify the overall energy system within which the infrastructure should function [40]. Another key idea is that, in order to find the optimal solutions, one must take into account how various sub-sectors interact with one another. A complete clean, green and sustainable energy system must be simulated using sophisticated energy modelling tools for making climate change plan more operational and detailed [41]. This has been accomplished through the significant use of Energy PLAN, which is a sophisticated energy system analysis tool.

The advantages of using this tool include the computations can be repeated by other scholars. The Energy PLAN tool is free and simple to use. It can run on a standard computer and is independent of any additional solvers or tools of a similar nature. This software is highly trustworthy. More than 300 peer-reviewed research articles employed the model till now, demonstrating how widely used it has been and continues to be. The model's applications include energy systems analysis and it perform modelling at the national, regional and global levels [42]. Many nations like China, Romania, Ireland, Croatia, Jordan, Finland, Iran, Serbia, and Denmark uses this tool with an emphasis on heat and electricity sectors [43]. Energy PLAN's theory and guiding principles make it appropriate for the analysis of complete clean, green and sustainable energy system. This tool offers a comprehensive list of relevant libraries includes forecasting demand, generation, emissions, smart grid integration, storage options, and conversion units between various energy sectors [44]. The application offers historical calculations with hourly time resolution for grid and storage systems. The calculation for storage use makes sure that chronological data is produced and that is documents the hourly charging, discharging, and utilization of different storage options. Energy PLAN is suitable tool in modeling complete energy system based on hourly resolution and this tool is much better as compared with other modeling tools includes LEAP, Homer, RET screen, MARKAL, and TIMES as presented in [45]. Complete guidelines on using Energy PLAN for modeling clean, green and sustainable energy system are given in [46,47].

## 3. Results and discussion

The actual recommendations for making clean, green and sustainable energy system have been broken down into four categories include residential and commercial (heat supply for homes and offices), electricity (balance of the entire electricity supply), industrial (services for large oil and gas industries) and transportation (services for aircrafts, ships and other type of transportation). The focus of these four categories are on four interconnected and cross-cutting themes include energy efficiency (complying with the EU energy efficiency directive), technological obstacles and development (identifying the most significant technologies and their possible roles in generating power), harnessing renewables (which kind and how much renewable energy should be needed), and sector integration (this includes the integration of the grids for electricity, gas, and district heating, as well as the storage, conversion, and electrification of energy).

Sweden produced 1,913,395.975 tera-joule of energy in 2020, which is increased by 13.68% since 1990. Sweden consumes 761.7 TWh and produces 32.14 million tone of $CO_2$ emissions in 2020. As can be seen, Already Sweden has a small proportion of biomass (527,518 tera-joule) and solar, wind etc (124,885 tera-joule) and a significant input of hydro (258,318 tera-joule) and nuclear power (533,629 tera-joule) of the country's electricity supply. Coal (65,975 tera-joule), oil (416,421 tera-joule), and natural gas (52,469 tera-joule) still make up a sizable portion of fossil fuel consumption. Particularly in comparison to other sectors, the share of fossil fuels is particularly significant in the manufacturing and transportation sectors. In Figure 2, a Sankey diagram depicts the existing state of affairs in Sweden as of the year 2020.

As previously said, we got some input from valuable professors and technological experts in making concerned plan through back-and-forth communication, which resulted in the development of various specific suggestions. The results are compiled by taking valuable suggestions of experts

and also by taking output of Energy PLAN software. Results cover all interconnected and cross-cutting themes for the year 2035 and 2050 include:

1. Efficiency in energy use, particularly compliance with the EU directive for energy efficiency: Under this theme savings in buildings are noticed (10% saving till year 2035 and 27% saving till 2050), steady adoption of latest generation heating, which will boost the use of waste heat from industrial operations and improve energy conversion unit efficiency while reducing the grid loss of the district heating system (50% till 2035 and 100% till 2050), improvements in efficiency brings savings up to 10% till 2035 and 30% till 2050 for industrial energy usage, increased use of energy-efficient technologies in data centers, which reduced electricity use by 3%, a reduction in private vehicle mileage growth compared to the baseline prediction (1.4 percent/year vs. 1.8 percent/year), as well as comparable cost reductions from modular switching from private vehicles and aviation to railroads and public transportation and finally, by using more energy efficient technologies, there will be a 8% reduction in "traditional power usage" in 2035 and a 18% reduction in 2050.
2. Technological obstacles and development: Under this theme combined heat and power (CHP) plants will be maintained in future. Trash, wood and biomass based CHP plants will be upgraded and used till 2050, as well as flexible gas-fired CHP plants for backup during times of low solar and wind potential. Waste to energy technique will produce 175 MW of power till 2035 and 1800 MW till 2050. Furthermore, up-gradation of biogas plants would help to add 30 peta-joule till 2035 and 55 peta-joule till 2050.
3. Harnessing renewables: Under this theme, solar heating is used to supplement heat pumps in the district heating system. Geothermal district heating should be another option with a 400 MW capacity in 2035 and an 800 MW capacity in 2050. The amount of PV systems will increase from roughly 900 MW in 2020 to 4,000 MW till 2035, and then to 8,000 MW till 2050. To minimize the amount of land needed for PV systems, the PV systems should predominantly be on huge roofs. Onshore wind power will increase from 4,000 MW in 2020 to 4,600 MW till 2035 and 5,800 MW till 2050. On the other hand, the amount of offshore wind power will increase from roughly 1,800 MW in 2020 to 6,400 MW till 2035 and then almost 12,800 MW till 2050. Finally, wave power will reach 120 MW till in 2035 and in 2050, it will remain with wind as a backup.
4. Sector integration: Under this theme, efficient technologies are used for integrating sectors depending upon the greater heat density areas. District heating and individual heat pumps will gradually replace oil and gas boilers because in future the heating demand of district heating will raise to 63%. The extra demand of district heating will meet by using solar thermal, which can provide 16% of the yearly heating demand. Utilizing adjustable and efficient electrical consumption units to balance wind, solar, and wave power. This primarily relates to intelligent electric vehicles that charge when it is appropriate for the energy system, heat pumps connected to heat storages in individual homes and district heating.

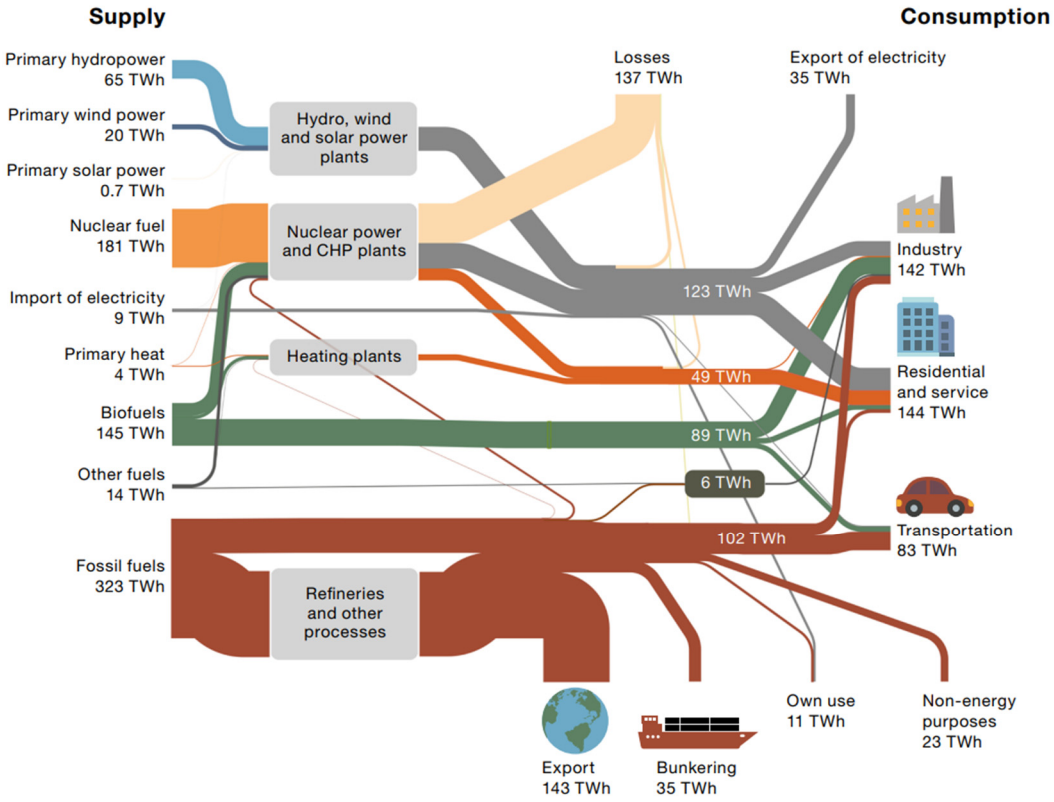


**Figure 2.** Shows the Snaky diagram of Swedish energy system for 2020.

The clean, green and sustainable energy system relies heavily on the usage of wind and solar energy in addition to Sweden's part of the world's sustainable biomass resources. This is in line with comparable scenarios for Central and South America, as well as Europe and other parts of the world. Sweden may in the future export wind to other European nations because it has good wind potential. The results of Swedish energy system for the year 2035 is outlined in Figure 3. As can be seen, there will be a significant decrease in solar power and suitable increment in wind power. However, a decrease in biomass would be necessary to attain a sustainable level. The transportation industry would be the primary user of the last remaining fossil fuels in 2035, and there would be none left by 2050. Electric vehicles are at high priority that use electricity directly for transportation. To meet every need, liquid fuel would still be necessary. Renewables will play a significant role in making clean, green and sustainable energy system, particularly in 2050. Furthermore, the results of Swedish energy system for the year 2050 is outlined in Figure 4. The most significant changes from 2035 are the complete phase-out of fossil fuels. As a result, electro fuels in conjunction with direct electrification of the heating and transportation sectors play a significant role. The clean, green and sustainable energy system of Sweden will transceive electricity with other nations because of mutual benefit in 2035 and 2050. For example, by sending electricity generated by wind to Denmark to help Denmark's sizable dams hydropower capacity consume less water. Import happens when an additional capacity is required, and export happens when there is extra renewable power available in the output of system.

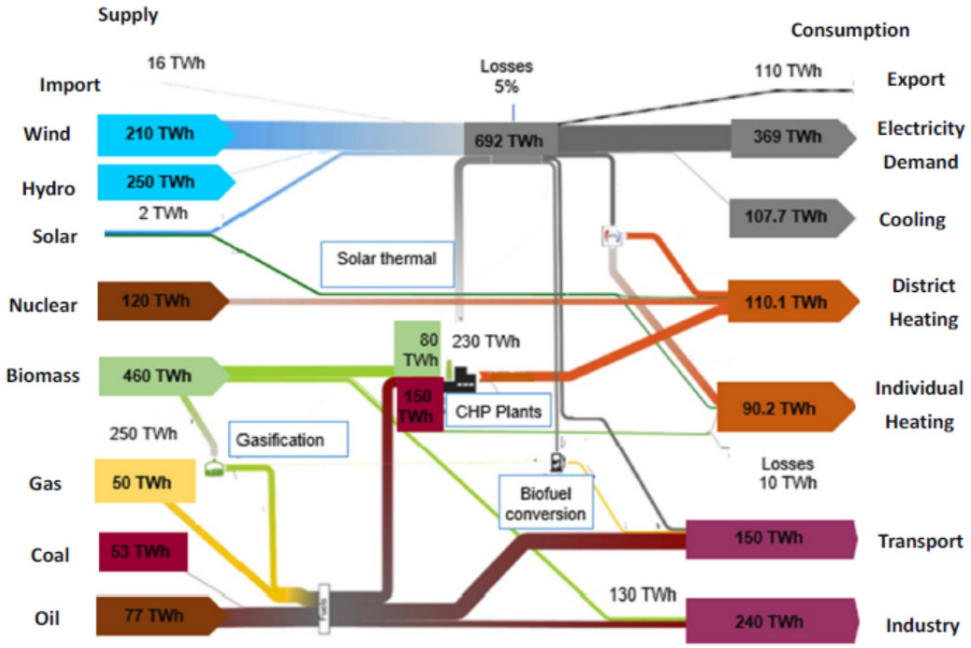


**Figure 3.** Shows the Snaky diagram of Swedish energy system for 2035.

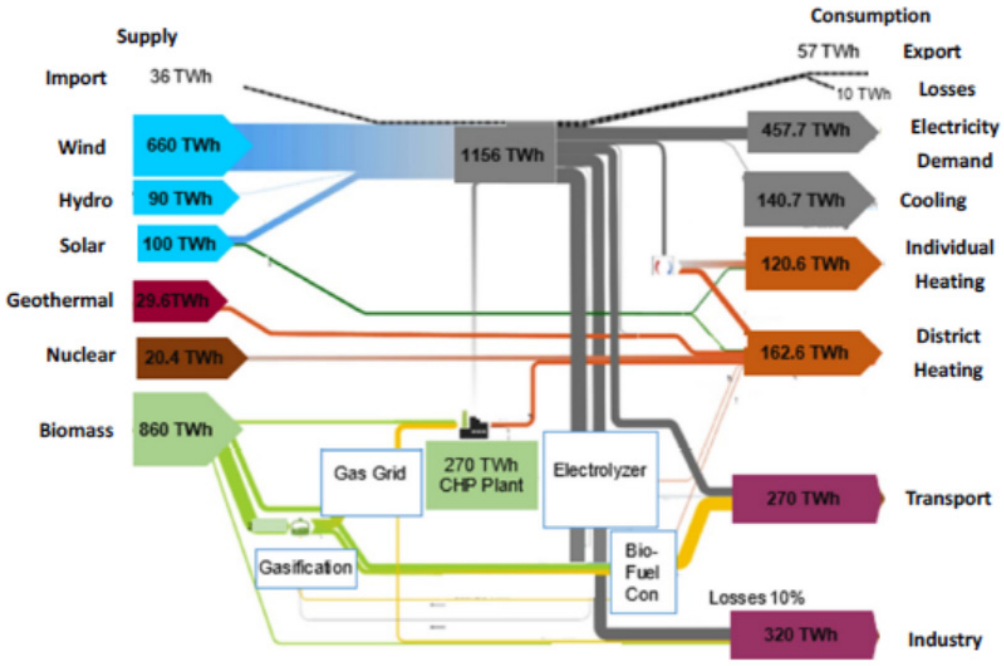


**Figure 4.** Shows the Snaky diagram of Swedish energy systems for 2050.

In this study, the use of renewables for power generation is facilitated and also greater emphasis to use renewable based power for sustainable development. However, fossil fuels are discouraged for power generation because of reducing carbon emissions which is considered as primary pollution.

On the other hand, global warming is also increasing due to secondary pollution which is due to the disposal of decommissioned facilities and uninstallations [48,49]. Secondary pollution can be reduced by recycling of decommissioned material or also by thermal treatment [50].

For the promotion of environmentally responsible production systems, everyone must understand that energy is at the heart of the climate challenge and key to the solution. A large chunk of the greenhouse gases that blanket the earth and trap the sun's heat are generated through energy production, by burning fossil fuels to generate electricity and heat [51]. Fossil fuels, such as coal, oil and gas, are by far the largest contributor to global climate change, accounting for over 75% of global greenhouse gas emissions and nearly 90% of all $CO_2$ emissions. The science is clear, to avoid the worst impacts of climate change, emissions need to be reduced by almost half by 2030 and reach net-zero by 2050 [52]. To achieve this, we need to end our reliance on fossil fuels and invest in alternative sources of energy that are clean, accessible, affordable, sustainable, and reliable. Renewable energy sources which are available in abundance all around us, provided by the sun, wind, water, waste, and heat from the earth are replenished by nature and emit little to no greenhouse gases or pollutants into the air. Fossil fuels still account for more than 80% of global energy production, but cleaner sources of energy are gaining ground. About 29% of electricity currently comes from renewable sources. Here are five reasons why accelerating the transition to clean energy is the pathway to a healthy, livable planet today and for generations to come [53].

1. Renewable energy sources are all around us.
2. Renewable energy is cheaper.
3. Renewable energy is healthier.
4. Renewable energy creates jobs.
5. Renewable energy makes economic sense.

Economic policies such as rationalization of price subsidies, the clarification of property rights, and facilitation of technology transfer may help in achieving environmental sustainability. Rationalizing subsidies will save money, improves efficiency and can significantly lower pollution. Also, open access to environmental resources needs to be replaced with some ordered system of use or ownership rights. Community ownership of resources can result in sound environmental stewardship, particularly where it is based on customary social practices.

## 4. Policy implications of sustainable energy systems

The key points are listed below for policy implications of sustainable energy system:

- Technical advancements will help to achieve objective of de-carbonization till 2050 for developing and under-developed nations.
- Should guarantee a level of energy efficiency in compliance with the relevant EU directive.
- Attempting to achieve the 50% $CO_2$ reduction target by 2035 in a socioeconomically effective manner.
- Number of newly created jobs in the renewable energy industry will increase.
- And finally, in order to guarantee widespread public participation in the achievement of these political objectives.

## 5. Limitations and future recommendations for sustainable energy systems

Few limitations of this study are listed below:

- The exact $CO_2$ emissions are not forecasted for the period 2035 and 2050.
- The implementation and running cost for the development and operation of clean, green and sustainable energy system is not incorporated in this study.

Recommendations for future research are listed below:

- Develop climate plan with the broader vision of energy mix, energy balance, energy transition and security of the supply.
- Integrate the climate and energy policy with the help of dedicated council, agencies, ministries and concerned municipalities.
- Limit the $CO_2$ emissions by exploring green energy sources and also by applying tax.
- Measure the climate impact on the economic sectors in terms of atmospheric degradation and cost effectiveness.

## 6. Conclusions

To develop a de-carbonization strategy for a nation to achieve a fully clean, green and sustainable energy system by the year 2050, we have discussed and provided a set of recommendations in this paper and then we have applied this framework to the instance of Sweden. A key component of the recommendations would require each nation to achieve its goals for greater renewable energy in a way that would reasonably enable the rest of the world to do the same. Additionally, a nation should achieve its short-term goal of renewable generation in a fashion that can eventually result in a fully decarbonized civilization. This could be achieved by integration of intermittent green sources like solar, biomass, geothermal and wind into the national electric supply. These broad criteria of de-carbonization indicate a number of options and problems, which can be minimized through government or nation to contribute in terms of affordability and also exploring reserve capacity of renewables.

Governments of various nations should include innovative efforts for carbon neutral technologies that would be required in the long run. These efforts have been used in the situation of Sweden till 2050 for achieving clean, green and sustainable energy system. Energy PLAN software is used for complete analysis of energy system under the 2035 and 2050 scenarios. 2035 scenario suggested that carbon emissions will be reduce by 50% and 2050 scenario suggested that carbon emissions will be reduced by 100%. In the 2035 scenario, fossil fuels provide energy around 180 TWh, whereas, renewables provide 642 TWh of energy. Under the 2050 scenario, fossil fuels contributed almost negligible energy (20.4 TWh), all the energy demand (1,471.6 TWh) will be meet with the renewables (1,739.6 TWh). Maximum energy demand is meet with the use of sustainable biomass and also the exchange of electricity is facilitated with nearby nations under both scenarios. The analysis takes into account all the demand sectors, including transportation, industrial, commercial, and residential. Additionally, the energy system works in tandem with other industries to create a fully carbon-free society. Therefore, in the article, we contend that, given a suitably aggressive timeframe, a green transformation of the Swedish economy and society is feasible, economically responsible, and practical. It would necessitate, long-term public investments in a

green transformation of the entire energy system, as well as encouragement for public and private sector.

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**Conflict of interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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