Two sides of the same coin? The Energy Transition Potential in Global North and Global South Countries

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Abstract

Background

Climatic changes have made transition to renewable energy essential. However, energy transition in the globalized world is challenged with diversification in culture, economic prowess, social development, and state structure. The global negotiations are always tough, among others, due to the split between the Global North (*GN)* and Global South *(GS)* countries. At the same time, the debates on how to deal with the inequalities in climate mitigation potential veils a thus far hardly acknowledged difference in energy transition potential and impact in the GN and GS countries. This paper, therefore, aims to contribute to bridging this knowledge gap by making a systematic comparative assessment of energy transition potential in the GN and GS with two regions as example cases.

Method

We used EnergyPLAN, the widely used energy model tool developed by the Sustainable Energy Planning Research Group at Aalborg University, Denmark. EnergyPLAN models a smart energy system, while analysing the energy balance, resource utilization, techno-economic cost, and carbon emission of the overall energy system (EnergyPLAN, 2017). The analysis has been conducted under the assumption of energy neutrality in 2050 with priority for renewable based technologies, minimalization of electricity import and export and optimizing fuel balances (EnergyPLAN, 2017).

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Results

We analysed and compared energy scenarios in two regions in the world: Overijssel representing the GN countries and Matura representing the GS south countries. Both regions are similar in economic activities, but differ in demography and economic development. We analysed and compared the current energy system in both regions and two development scenarios towards 2050: the BAU scenario and the zero emission scenario. Despite the differences in starting position, the energy systems in both regions move towards each other in the longer term, but change pattern and costs differ.

Conclusion

In both regions bioresources are the dominant renewable resource in an locally determined energy resource portfolio. However, the costs of getting into this longer term position are significantly higher in Matura than in Overijssel, whereas the general economic potential, as it looks in 2020, is worse in Matura. Our analysis therefore indicates that a renewable energy transition in the longer term can result in zero emission systems in both GN and GS countries, but with substantial differences in costs.

1. Introduction

Under the COP 21 Paris Agreement, countries need to make a transition to renewable and sustainable energy away from fossil fuels. The negotiations are always tough, among others, due to the split between the Global North (*GN)* and Global South *(GS)* countries. The Global North, roughly referring to the industrialized world with stable states, well-developed economies and high quality of life (Eriksen, 2015) are focused on green agendas (Kemmler & Spreng, 2007), i.e., the sustainability of environment, resource degradation and waste aggregation (Savage, 2006). On the other hand, the Global South roughly referring to developing and under-developed countries, emphasize brown agendas. This includes poverty, lack of food, poor education and healthcare, human and civil rights abuse, ethnic and religious violence (Ming'ate, 2015), pollutants, waste hazards, lack of infrastructure and unequal distribution of resources and wealth. These developmental issues for the GS, are rendered as social issues for the GN (Collins, 2000). Moreover, when analysed empirically, we observe this division with low level of productivity, increasing population size, agricultural production rate and inadequate power in international relations from the GS (Odeh, 2010).

As a result, the climate mitigation potential of both country blocks appears to be quite different. At the same time, the debates on how to deal with the inequalities in climate mitigation potential veils a thus far hardly acknowledged difference in energy transition potential and impact in the GN and GS countries. This is only indirectly debated as a development issue with respect to GS countries, saying that these countries need room for economic development to be able to invest structurally in climate mitigation. With respect to energy this means transforming the current dominance of fossils in energy production and consumption into a renewable one. What is less known in this transitional debate is the actual potential of countries to change its current energy system into a renewable one. Wind, sun, water and bioresources are considered as the renewable resources for energy production and consumption and to date only Global North countries and China have been successful in increasing the share of these renewables in energy production.

Several international organizations like the IEA or IRENA publish country wide scenarios with respect to renewable potential but how these scenarios translate to the regional arena's where the energy transition is supposed to be implemented is less know. This paper, therefore, aims to contribute to bridging this knowledge gap by making a systematic comparative assessment of energy transition in the GN and GS with two regions as example cases. Our research is guided by the following research question: **What are the differences and similarities in the regional sustainable energy transition in the Global North and Global South, with the region Overijssel in the Netherlands and the region Matura in India as illustrative examples?**

The question is answered as follow. The section of the paper analyses and compares the energy transition dynamics in the GN and GS countries based on literature. The general idea of energy transition in both parts of the globe are specified for two example regions: Overijssel in the Netherlands representing the GN and Matura in India representing the GS. The energy transition potential in both regions is systematically analysed and compared with the help of the energy transition scenario. The scenarios are modelled on the basis of the economic activities, societal development, regulations, and technology availability and simulated on EnergyPLAN software. The scenarios allow to systematically compare the energy potential in both regions in the world and to answer the central research question.

2. Global North and Global South: Differences in Energy Context

The term Global North and Global South was introduced during the post-cold war era to signify the developed and the developing or under-developed countries globally. The developed countries in the world were kept in the frame of GN as they were majorly from the northern hemisphere but also had countries like Australia and New Zealand from the South. While the under-developed and developing countries were placed in the bracket of GS. This distinction is not purely based on geographical locations and neither on income, GDP *(Gross Domestic Production)* or *HDI (Human Development Index).* Instead, it shows a difference in the public sector, state organization, economic development, industrial development , social development, and equal share of resources between the globalized world (60 Second guide to the Global North/South Divide).

These differences can also be witnessed in the context of energy consumed, possibilities to sustain secure energy supply and variation in carbon emissions between GN and GS countries. Historically, human progression and state development has been linked with the availability and consumption of energy. In the last two centuries we have observed exponential rise in energy consumption due to industrial development (Sørensen, 2012). This increase in consumption has been unequal among countries (Arto, Capellan-Perez, Lago, Bueno, & Bermejo, 2016) and between different social classes within the same state.

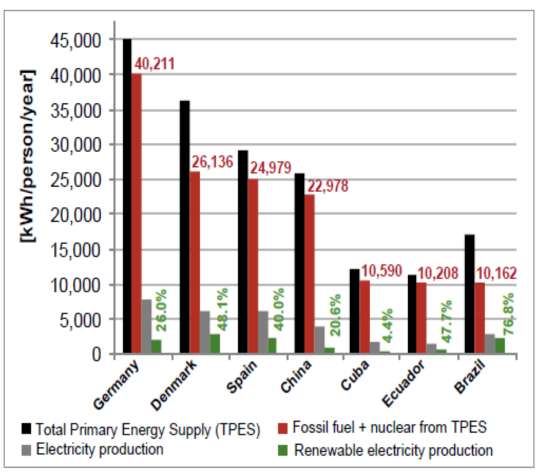

Figure 1: Primary Energy Supply per person every year in different countries signifying the differences in the GN and GS.

As we observe in the figure 1 a considerable difference in the total energy supply per person per year between the GN countries like Denmark and Germany and the GS countries like Cuba and China. This can be related with industrialization and security of supply in the developed world. On the other hand, when we interlink the energy supplied with equivalent carbon emission per person per year between these countries in figure 2, we observe a similar difference with the GN having a higher share of emission.

However, we witness a decline in the emissions in figure 2 for Germany and Denmark, while increase in emissions in China, Brazil and Ecuador signifying a probable hidden energy flows *(HEF)*. The ecological debt with these HEF, impacts the society and environment in the GS (Akizu, et al., 2017). Consequently, the emissions globally remain the approximately the same.

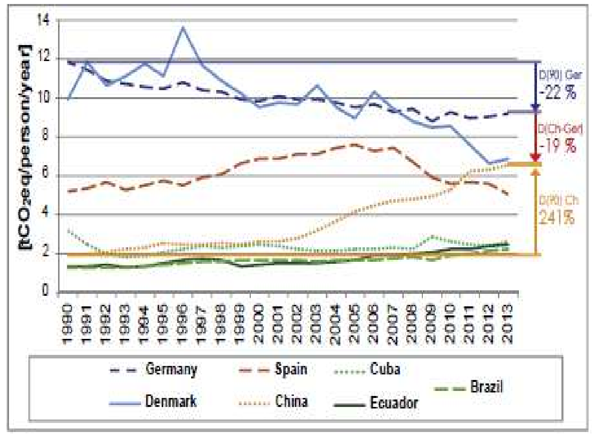

Figure 2: CO2eq emission from fuel consumption for the energy supply of globalized countries.

In addition to that, the distinction in the globalized world is also observed on the interpretation of energy poverty. In the GN, energy poverty is related to the implications of affordability of the primary energy requirements (Sen, 2014). Higher prices for energy specifically thermal comfort in the GN can make it unaffordable for local public leading to poor health or reduced expenses to meet other needs of a household (Day, Walker, & Simcock, 2016).

For the GS, energy poverty holds a different explanation as the states are unable to provide reliable energy services due to lack of the energy infrastructure (Sen, 2014). Billions of people do not have access to energy, clean water, safety and food security and the focal point is to get access to energy to provide these amenities (Day, Walker, & Simcock, 2016). Often the local households in the GS are dependent on raw biomass and fossil fuels for daily activities. Utilizing these resources generates pollutants that has a more profound effect on the health of women and children (Bruce, Perez-Padilla, & Albalak, 2000). Additionally, collecting these resources by personals in the rural areas is time-consuming that does not result in knowledge and income and further reduces their productivity level (Day, Walker, & Simcock, 2016).

The sustainable energy transition can be at the forefront of overall development in the globalized world for their respective green and brown agendas. Through the medium of transformation to renewable energy the GN can optimize their ways of energy consumption through innovation without compromising the economic resilience and quality of life (Arto, Capellan-Perez, Lago, Bueno, & Bermejo, 2016). Thus, reducing their equivalent carbon emissions and enhancing environmental and resource sustainability. On the other hand, the GS can make a switch to renewable energy improving their energy infrastructure through distributed generation system and improve their economic growth and standard of living for their citizens.

However, transition in the energy system is challenged by geographical locations, demography, economics and politics along with culture and historical traditions (Laurie, Andolina, & Radcliffe, 2005). The GS presents challenges to energy transition with inefficient energy data collection and the energy acquisition illegally through black market (Day, Walker, & Simcock, 2016). Additionally, the implementation of renewable energy in the GS is deterred by corporate greed. For instance, the hydroelectricity plant in Brazil occupied the land from the locals and transferred it to the corporates. The prices of the energy generated remains high and the wealth generated is kept by the owners, while the workers are exploited, and no benefits are transferred to the displaced locals.

On the other hand, the energy transition in the GN presents different challenges. The data availability and studies provide support to technological innovations and transition. However, there are limitations in the process through excessive consumption, strict policies, and societal approval. For instance, the European Union regulates the use of land for bioresources and the Dutch government imposes similar regulations on cattle farmers and manure disposal. Another example to present difficulty in societal approval is the case of NIMBY *(not in my backyard*), a phrase used by the locals to avoid having wind turbines and bioenergy systems near their houses.

Further, the distinction can also be observed with the implementation of sustainable energy technology in the globalized world. The regions in the GN are more lenient towards a bottom-up approach or a democratic and social awareness approach, which are beneficial due to high rate of education and socio-economic equality. Meanwhile, the GS would be more lenient toward the top-down approach due to poverty, low literacy rates and inequality. Although, more developed Global South states also have an option to imply a democratic and social awareness approach.

Energy development is a wholly relative and context-dependent concept with all the regions in the globalized world share the spatial imbalances in geographical concentration related to economic growth, societal development and cultural values (Pike, Rodríguez-Pose, & Tomaney, 2014). It is challenging to integrate a single transition model that reduces emissions while supporting the economic growth, as multiple social processes will have a different preview from diverse disciplines (De Paula & Dymski, 2005). The current techniques and plans are formulated for the GN, while there is a minimal study on energy transition in GS. The ideas of sustainable development in the GN will not work in the GS (Rana, 2009).

3. Methodology

To present the empirical results for the differences and similarities in sustainable energy transition between the Global North and South, two regions from the globalized world are examined as a case study. The GN is represented by the Dutch province of Overijssel and the GS is represented by the Indian region Mathura.

We used EnergyPLAN, the widely used energy model tool developed by the Sustainable Energy Planning Research Group at Aalborg University, Denmark. EnergyPLAN models a smart energy system, while analysing the energy balance, resource utilization, techno-economic cost, and carbon emission of the overall energy system (EnergyPLAN, 2017). The analysis has been conducted under the assumption of energy neutrality in 2050 with priority for renewable based technologies, minimalization of electricity import and export and optimizing fuel balances (EnergyPLAN, 2017). The data requisites of EnergyPLAN are high which resulted in quite some missing values for Mathura and to a lesser degree for Overijssel. The missing data for Mathura have been indirectly gathered from governmental agencies and by extrapolating several available statistics like monthly electricity data for Mathura procured from Dakshinanchal Vidyut Vitran Nigam Limited (DNVVNL*) (Appendix A)*.

Moreover, for both regions the predictive energy data for the year 2050 have been extrapolated by energy reports of the Netherlands and India and deduced for the regions based on historical data (Overijssel) and base load scenario (Mathura). The Appendix A explains in more detail the data used in the analysis.[2]

The energy model simulations are conducted for three scenarios namely the reference scenario for the current energy system, the business-as-usual scenario for the year 2050 for autonomous development of the current energy system and the energy transition scenario for 100% renewable energy share by the year 2050.

4. Global North and Global South: Two representing regions

The region from the GN is the Dutch province of Overijssel located in the east of the Netherlands sharing its eastern border with Germany. The province covers a land area of 3,327 km^2, with a population of 1.15 million as of the year 2019. The gender ratio in the region is approximately equal and the average population age is 40 years (Province of Overijssel, 2019). The province of Overijssel

[2] The full explanation of the methodology can be found in Jain, Schrutir, **ENERGY TRANSITION IN GLOBAL NORTH-SOUTH DIMENSION:** CASE OF OVERIJSSEL AND MATHURA, Enschede 2020 (master thesis)

has half of its population living in urban cities, while the other half is living in rural areas with agriculture and tourism as core economic activities.

The energy supply in the Overijssel is accounted to be 102.8 PJ for domestic, commercial and transportation in the year 2015 (Beursken, Reffeltrath, & Menkveld, 2016). Among the energy delivered, only 9% of energy is generated from renewable energy sources that include wind, solar, geothermal, bioenergy and biofuels. The rest of the energy is generated by fossil fuels like coal and natural gas and imported from outside the region. See table 1.

Total Energy Demand in Overijssel *(Year 2015)*	**28.5 TWh**	
Household	7.7 TWh	
	1.6 TWh *(Electricity)*	5.2 TWh *(Heating)*
Commercial/ Industries	11.1 TWh	
	2.5 TWh *(Electricity)*	7.5 TWh *(Heating)*
Transportation	9.4 TWh	
Energy derived from Fossil fuels or imported	**25.8 TWh**	
Total Renewable Energy Generated	**2.6 TWh**	

Table 1: Energy consumption and generation source in Overijssel

The second region, representing the GS is the Mathura district located in the northern part of India in the Uttar Pradesh state. The district covers an area of 3,329.4 km^2, with a population of 2.54 million as recorded in the census in the year 2011. The region is famous for its religious heritage and attracts tourists throughout the year. The region is a combination of rural and urban cities connected with public transport. The gender ratio in the region is unbalanced towards males and has a literacy rate of approximately 72%. The region has a strong base for agriculture and cattle farming. Approximately 75% of the land available in the region is utilized for agriculture and cattle farming *(Appendix B)*.

The energy demand in the region is sufficed through importing electricity by thermal power plants from adjoining districts that provides electricity 24 hours a day with minor interruptions. While LPG for cooking and petroleum for transportation fuel is imported majorly from the middle east countries with minor generation from other parts of the country. Table 2 shows the approximate energy data.

Estimated Energy Consumption in Mathura District	**4.3 TWh**
Electricity Consumption	1.9 TWh
LPG consumption	0.7 TWh
Biomass Consumption for Cooking	0.38 TWh
Transportation	1.3 TWh
Energy derived from Fossil fuels or imported	**4.3 TWh**
Total Renewable Energy Generated	**0 PJ**

Table 2: Energy consumption and generation source in Mathura

When we examine the equivalent carbon emission and the estimated techno-economic cost in table 3 for the energy systems of the two regions, we empirically observe a significant difference between Overijssel and Mathura.

Reference Scenario	Overijssel	Mathura
Eq. Carbon Emission *(Mton)*	7.09	2.37
Techno-Economic Cost *(in million €)*	€ 1540 million	€ 168 million

Table 3: Distinction in Carbon Emission and Techno-Economic Cost for Reference Scenario between Overijssel and Mathura

Overijssel has higher emissions and cost as compared to Mathura due to the distinction in the energy profile that confirms the differences in energy context between GN and GS countries. As will be shown below, these differences continue in the future when both regions are transforming their current energy system into a renewable based sustainable one, despite the better position of Mathura with respect to availability of renewable resources. From table 4, we can see the differences in the amount of annual energy potential of resources between the two regions.

Renewable Energy Resource	Annual Energy Potential	
	Overijssel	Mathura
Bioenergy Potential	12.64 TWh	27.15 TWh
Pruning Wood	*6.6 TWh*	*0.47 TWh*
Organic Feedstock	*1.83 TWh*	*6 TWh*
Agriculture Waste	*0.35 TWh*	*> 16.5 TWh*
MSW	*3.86 TWh*	*4.18 TWh*
Solar Energy Potential (Panel η=18%)	182 kWh/m²	354.19 kWh/m²
Wind Energy Density	240 kWh/m²	200 kWh/m²
Geothermal Energy Potential	0.72 TWh	-
River Hydro Energy Potential	-	0.26 TWh

Table 4: Available renewable energy resources in Overijssel and Mathura (Appendix B)

As we can see from table 4, except for wind, Mathura's position in all other renewable resources is far better than the position of Overijssel. In particular biomass and the sun provide high renewable potential in Mathura if the region is able to exploit the renewable resources. Moreover, here the difference in economic position and energy context will be a hindering factor to benefit energetically from the rich renewable resource potential in the GS region. The next section will show this point by two scenario analysis we did for both regions. One scenario showing the Business as Usual (BAU) and one scenario assuming a complete renewable based energy system in 2050.

5. **Energy Transition Scenarios in Overijssel (GN) and Mathura (GS)**

This section analyses and compares the regional sustainable energy transition potential in Overijssel and Mathura in two scenarios. The first scenario is the BAU scenario, which represents the autonomous energy developments in both regions. Renewables resources can but need not be part of this autonomous development. Given the current domination of fossil resources in both regions, it is not unrealistic to assume a continued application of these resources in the coming decades. Our second scenario is a 100% renewable based energy system in 2050, without any direct carbon emissions.

Business-as-Usual Scenario

The possible development in energy consumption for the GN region Overijssel and the GS region Mathura for the year 2050 under the BAU scenario can be seen in the Table 5.

ENERGY DEMAND	BAU	
	Overijssel	Mathura
Electricity Demand *(in TWh)*	4.02	7.17
Cooking Fuel Demand *(in TWh)*	-	1.6
Heating Demand *(in TWh)*	5.21	-
Industrial Fuel *(in TWh)*	7	-
Transportation Fuel Demand *(in TWh)*	10.5	8
Total Billion km/yr	*20*	*12*
Total Energy Demand *(in TWh)*	**26.73**	**16.77**

Table 5: Comparison between the expected energy demand in Overijssel and Mathura in BAU scenario

A study from KIVI Engineering society understands that the energy consumption for Netherlands will show marginal deviation in the year 2050, if similar trends of energy system transition is followed. The possible rise in consumption per person to maintain quality of life that is neutralized by determination to improve their energy efficiency. Based on this study, we made a similar assessment for Overijssel owing to historical trends[3]. On the other hand, Mathura will witness a spike in its energy consumption due to growing population and GDP growth influencing the quality of life and therefore energy demand according to World Energy Annual Report 2018-2050.

To satiate these energy demands, the BAU scenario is simulated *(Appendix C)* and table 6, shows the resource utilization to generate energy in both the regions,

[3] See reference in footnote 2 above.

Resources	BAU	
	Overijssel	**Mathura**
Coal	3.7	18.14
Natural Gas	18.67	2.57
Petroleum Fuel	5.9	5.6
Solar Energy	0.23	0.28
Wind Energy	0.18	0
Geothermal Energy	0.13	0
Bioresources	4.9	2.2

Table 6: Resources utilized for energy generation in Overijssel and Mathura in BAU scenario

Overijssel should be expected to have approximately 15% of the renewable energy share in the BAU scenario considering the current pace of energy development and planning by the provincial government. Natural gas will remain the dominant energy resource for the province. On the other hand, Mathura will only be able to add 8.5% of renewable energy share to their total primary energy supply. Coal will be the dominant resource for energy generation, while the renewable energy share will majorly consist of wet biomass from animal feedstock and high solar irradiation.

Based on the resources utilized and the system implemented, we observe the equivalent carbon emission and annual techno-economic cost as results of the autonomous development of energy system between both the globalized regions in table 7.

Business-s-Usual (Year 2050)	Overijssel	Mathura
Eq. Carbon Emission *(Mton)*	6.27	8.43
Total Annual Cost *(In million €)*	€ 2257	€ 1381

Table 7: Distinction in equivalent Carbon Emission and Techno-Economic Cost for BAU Scenario between Overijssel and Mathura

The GS region Mathura will have a higher carbon emission than Overijssel as their energy consumption increases. Although, the energy consumption in Overijssel is still higher than Mathura, but energy efficiency measures lowers the carbon emission in Overijssel as compared to the reference scenario. Additionally, the techno-economic cost of Overijssel for the BAU scenario will also remain to be higher than Mathura.

Energy Transition Scenario for 2050

The energy transition scenario for the year 2050 aims to attain energy neutrality for Overijssel and Mathura. The scenario is formulated based on the projected energy demand based on the proposed emission reduction and energy efficiency targets and expected economic and societal growth for the particular region that can be seen in table 8.

ENERGY DEMAND	BAU	
	Overijssel	**Mathura**
Electricity Demand *(in TWh)*	2.27	7.32
Cooking Fuel Demand *(in TWh)*	-	1.6
Heating Demand *(in TWh)*	2.64	-
Industrial Fuel *(in TWh)*	4.6	-
Transportation Fuel Demand *(in TWh)*	4.04	3.12
Total Billion km/yr	*20*	*12*
Total Energy Demand *(in TWh)*	**13.55**	**12.04**

Table 8: Projected energy demand for Overijssel and Mathura in the Energy Transition Scenario 2050[4].

The study by KIVI engineering society also understands that, if the Netherlands can achieve their emission, energy efficiency and renewable energy targets, their energy consumption can reduce by 50% by the year 2050 (Persoon, Luitjens, Boonstra, & Moerkerken., 2017) and consequently a similar trend can be assumed for Overijssel. On the other hand, World Annual energy report 2017 predicts higher energy consumption for India and consequently Mathura due to economic growth and rising population index (Li, 2018).

The energy system is modelled considering the resource potential of the two regions and the results of the simulations *(Appendix C)* can be seen in Table 9.

[4] See reference in footnote 2 above.

Energy Transition 2050	Overijssel	Mathura
Energy Generation Resources (in TWh)		
Solar Energy	*2.86*	3.41
Wind Energy	*0.84*	0.40
Run-Off River Hydro	-	0.26
Geothermal Energy	*0.88*	-
Bioresources	*16.63*	22.63
Electric Battery Technology (in GWh)	9	12
Heating Storage	5	-
Carbon Emission (Mton)	**0**	**0**
Annual Techno-Economic Cost (in million €)	**€ 887**	**€ 1207**

Table 9: Distinction between Energy Generation Resources, Carbon Emission and Techno-economic Cost for the Energy Transition 2050 scenario between Overijssel and Mathura

The energy neutral scenario results in a carbon neutral energy system for both the regions. However, when we observe the techno-economic cost, Mathura presents a high cost as compared to Overijssel. The energy system in both regions is dominated by bioresources due to their economic activities. The green gas produced in Overijssel can be used as an alternative of natural gas for thermal comfort, while for Mathura it would suffice the need for cooking fuel.

Furthermore, access to bioresources are limited to suffice the complete energy demand in both regions. Therefore, diverse energy systems utilizing different resources available in the region have to be added in the energy planning. Moreover, both the regions intend to make a transition to electric vehicles (Chao, 2017) (Mission Zero, 2019) to integrate larger share of renewables and improving the energy efficiency. Though the transportation sector will marginally be supported by biofuels and green gas.

For Overijssel, sun, geothermal and wind resources are to be used to provide additional energy. The energy efficiency will be improved by formulating a synergy between consumption and generation sections by expected technological development. This would in turn reduce the energy consumption leading to reduction in economic cost and emissions. The alternative energy system other than bioresources can be further increased, but they might face limitation with grid stability. Therefore, further research and technological advancement are required in energy generation and storage to supplement the shortfall as the bioresources in Overijssel might not be sufficiently available for this energy neutral scenario.

For Mathura, with ample irradiation, the energy system will be supported by solar energy system and meagrely by wind energy and run-off river hydro system. The utilization of biomass is a priority as it would reduce the carbon emission that usually occurs from burning crop residue or dumping into landfills. Conversely, solar panels encounter barriers on the roof due to dense construction (DTE Staff, 2019), therefore commercial solar PV farm is required on fallow land and river coast, thus, not having an impact on the land footprint.

6. Implications of Sustainable Energy Transition

The realization for energy transition and attaining energy neutrality in both the Overijssel and Mathura are dependent on the regional approach considering regulations, economic strength, and social factors. Both the regions are dominated with agricultural and cattle farming activities making bioresources available for energy generation. Additionally, both regions are also influenced by strong tourism industry that demotivates the installation of inland wind turbines in the region. While the installation of solar panels is motivating in both regions and highly beneficial in Mathura due to warm weather conditions and ample sunlight.

However, on examining the implications socially, the energy system in Overijssel must make a transition by maintaining energy security and affordability of energy. It must be combined with a transition to energy-efficient industrial processes and homes in the region. However, social acceptance and regulations have a vital role in implementation of renewable energy technologies in the Dutch region. The challenges like NIMBY (not in my backyard) are experienced by the citizens and there are stringent political regulations in utilization of bioresources citing sustainability issues.

Contrarily, the energy transition in Mathura, is amiable to eliminate the shortage of power and growing health issues due to using of unsustainable energy resources. Therefore, the implementation of energy system is socially acceptable and the regulations from the government are cordial. Thus, the transition must be strategically planned by satiating the growing need for energy along with a transformation of the current energy system in place, providing a secure and reliable supply of energy as it was absent in the previous years.

There is proactive planning for transition in the GN and Overijssel as the province has pre-determined criterion for spatial zoning to installing renewable energy in the region (Hoppe, Dijk, & Arentsen, 2011). It involves diverse stakeholders and applies the democratic and social awareness approach. The GS region Mathura do not have a strategic plan for transition. The regions just participate in the national targets and do not emphasis on regional transition in the energy system. Any transformation in the region will be supported by a top down approach.

Furthermore, Mathura being in India is a part of booming economy yet is economically weaker in comparison to Overijssel. Therefore, considering the techno-economic cost in the energy transition scenario 2050, the energy transition in Mathura could be hindered economically. The GS region will not be able to invest much in research to accelerate the process of energy transition and continue to implement the existing technologies. Contrarily, Overijssel being part of the GN Netherlands is economically stronger that allows them to invest in research and technology innovation. Such investment results in advanced and affordable technologies that can accelerate the process of energy transition.

An example on the financial implication on energy system can be viewed in terms of transition in transportation sector. Based on the national targets, both regions aim to make a transportation transition from fossil fuels to electrical vehicles by the year 2030 (Chao, 2017) (Mission Zero, 2019). The integration of electric vehicle in Overijssel has been initiated with the introduction of public vehicle charging stations. However, the plan of electric mobility in India and Mathura is only at a primary stage.

7. Conclusion

The starting point of the paper was a lack of knowledge of how country scenarios on renewable energy transition translate to the regions where the energy transition is supposed to be implemented. Knowing the differences between the energy transition potential in GN and GS countries, we raised the question how these differences would manifest in the regions in countries belonging to the GN and the GS. Our guiding question was: **What are the differences and similarities in the regional sustainable energy transition in the Global North and Global South, with the region Overijssel in the Netherlands and the region Matura in India as illustrative examples?**

We started answering this question by analysing the differences between the Global North and Global South country blocks in the world. These blocks represent a clear demarcation in several global debates, among others on climate change and energy transition. The differences in particular manifest in economic and financial potential to modernise and sustain energy systems. However, a closer look at two representing regions, Overijssel for the GN and Matura for the GS also showed similarities in socio-economic outlook and renewable energy resource potential. Both regions have agriculture, cattle farming and tourism as major economic activities one a comparable geographical area with high bioresources potential. On the short term the differences between both regions showed to be substantial due socio-economic and demographic differences. These differences also showed in the comparison of the current energy system in both regions. However, looking ahead to 2050, the differences become smaller, in particular with respect to energy consumption and accompanying emissions and costs as analysed and compared in the BAU scenario. In Overijssel the energy consumption hardly changes due to continued efficiency improvements whereas the energy consumption in Matura increases due to increasing population and economic development. However, the energy portfolio in Overijssel also does not change significantly in the BAU scenario reducing the CO2 gap between Overijssel and Matura. The costs of the BAU scenario are significantly higher in Overijssel compared to Matura.

The comparison of the zero emission scenarios for 2050 continues the trend in the BAU scenario: the movement in both regions towards each other in a zero emission energy system development. In both regions bioresources are the dominant renewable resource in an locally determined energy resource portfolio. However, the costs of getting into this longer term position are significantly higher in Matura than in Overijssel, whereas the general economic potential, as it looks in 2020, is worse in Matura. Our analysis therefore indicates that a renewable energy transition in the longer term can result in zero emission systems in both GN and GS countries, but with substantial differences in costs.

Appendix A: EnergyPLAN Software and Input Data

EnergyPLAN software presents a medium to the research community to validate their energy transition scenarios. It has been used in researches to design and simulate national and regional energy planning strategies by formulating a synergy among energy systems (EnergyPLAN, 2017). Furthermore, the scenario timeframe required is one year with a one-hour time step and has the luxury to be combined and create a scenario for multiple years (Connolly, Lund, Mathiesen, & Leahy, 2010).

The acquisition of input data required to run the simulations in the energyPLAN model for the study and is described in this section

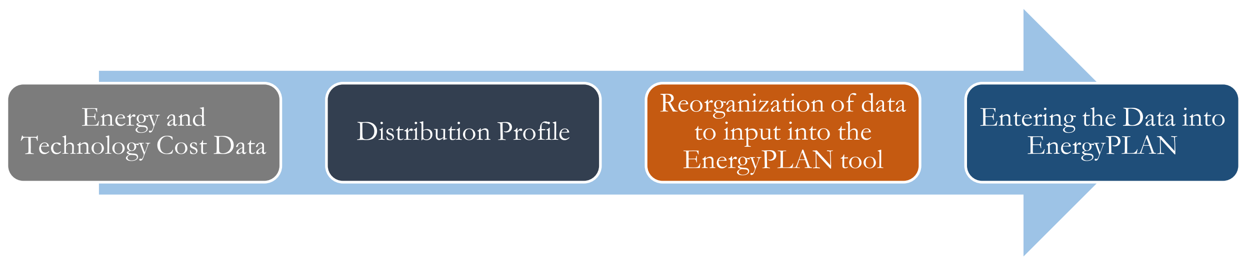

Figure 4.1: Process Flow for Data to be utilized in energyPLAN

Energy Data

The static data of the energy for the province of Overijssel is collected from the official website http://www.overijssel.nl and the previous year data for energy is collected from https://klimaatmonitor.databank.nl. The data collected includes energy consumption through electricity, heating and transportation across all sectors.

On the other hand, for the district of Mathura, the electricity data was collected by contacting the local authorities and was provided by Dakshinanchal Vidyut Vitran Nigam Limited (DNVVNL). The transportation consumption data is not available with the local authorities. Therefore, an assumption is based on contact with local authority and owner of a fuel station and presumed to be the same for all registered fuel station in the district. While the cooking fuel data is acquired from the official Assessment report on LPG cooking fuel by CRISIL: An S&P Global Company in June 2016.

The predictive energy data for the year 2030-2050 is not available for Overijssel and Mathura. However, there are different studies elaborating diverse energy scenario and expected energy consumption of the Netherlands and Mathura. Based on the historical trends for Overijssel and the

Netherlands, the energy consumption data for the years 2030-2050 is assumed with higher integration of renewable energy share and energy efficiency.

On the other hand, historical trend for Mathura and India is unavailable therefore, an expected energy consumption for the district is assumed with the trend of the reference scenario. Meanwhile, the energy consumption for business-as-usual and energy transition scenario is the same for Mathura with a view of development of 100% electrification along with growth in population, economy, and standard of living.

Obtaining Distribution Profile

The distribution profile is required to know the hourly energy demand and weather conditions to determine the energy supply from the renewable energy system. The energy consumption profile for electricity and gas for Overijssel is acquired from Liander. The downloaded distribution profile is a generic one from the year 2008 and assumed for the province. Additionally, the tool requires solar and wind data to evaluate the actual energy production from solar energy and wind energy systems. The hourly weather profile of Overijssel is downloaded from Meteorological Data Portal for TU Delft (https://www.tudelft.nl/). The dataset consisted of one year constructed from weather data averaged over a multitude of years, with a one-hour time resolution.

Table A1: Distribution Profiles and Data Sources for Overijssel

Distribution	Timespan	Source
Solar irradiance	Average 1991- 2018	TU Delft
Wind speed	Average 1991- 2018	TU Delft
Electricity demand	2008	Liander
Gas/heat demand	2008	Liander
Transport BEV	Basic Data Profile	EnergyPLAN
Constant	Value 1 for all hours	EnergyPLAN

The distribution profile for the Mathura region is not available due to administrative regulations. Therefore, the profile is formulated by using the Artificial Load Profile Generator (ALPG). ALPG is an open-source software developed by the University of Twente and simulates load profile for electricity and heating with constraints from controllable domestic devices. However, for Mathura, these controllable domestic devices are not used, and a basic electricity profile is developed based on the demographics of the city. The weather profile for the district is downloaded from Solar Radiation Data (SoDa) website (http://www.soda-pro.com/) and are at a one-hour time step.

Table A1: Distribution Profiles and Data Sources for Mathura

Distribution	Timespan	Source
Solar irradiance	2018	SoDa
Wind speed	2018	SoDa
Electricity demand	Monthly Average 2018	DNNVL
Gas/heat demand	Not Applicable	Not Applicable
Transport BEV	Basic Data Profile	EnergyPLAN
Constant	Value 1 for all hours	EnergyPLAN

Influence of data on Simulations

The results of the simulation are dependent on the data set and the distribution profile uploaded into the software. The energy distribution profile for Overijssel is from 2008, while the static data is current. An alteration in the results is expected if the current data set is used and applied for future scenarios. These alterations are due to changes in the behavior of consumers and the introduction of new and efficient appliances. Similarly, the data set for Mathura was not available with ease and needed to be extrapolated from one month, while the distribution profile is generated through ALPG. The software generates a comparable profile for the Netherlands. However, the societal differences between India and the Netherlands will generate a comparable difference in the manner of distribution.

Lastly, the simulations are influenced by the regulations criteria to reduce CEEP (Critical Excess Electricity Production) and to maintain the grid stabilization. The CEEP strategy for both the regions is selected separately, while the grid stabilization share has been the same for both the regions to 0.3.

Appendix B: Energy Resource Potential

This section estimates the energy resource potential for Overijssel and Mathura.

Bioresource Energy Potential

The energy from bioresources are evaluated and extracted from pruning wood, municipal solid waste, organic feedstock, and agriculture waste.

Pruning Wood Calculation

To simplify the calculation for availability of pruning wood, we take an assumption that both regions have oak tree (Tree species that are common in the Dutch woods., n.d.). Further, to have an estimation on total number of trees in one hectare of land, we use an online tree calculator with an average distance between each oak tree to be 10 feet (Tree Spacing Calculator, 2000).

The weight of an oak tree with 16 inches of DBH and 60 feet height is around 1 ton (David W. Patterson). A young tree can be pruned 25% and middle-aged tree can be pruned 20% while an old and mature tree can be pruned 10-15%. The pruning of wood is based on the photosynthesizing foliage to remain healthy and the tree can withstand the pruning. (Purcell, 2015)

Over here, we take the pruning of the wood to be 5% as both the region, which will vary in their pruning percentage and the weight of the wood. Therefore, the wood pruned from one tree is 5% of 1 ton = 0.05 ton with an average lower heating value of wood is 4.00 kWh /kg (Bisaglia, et al., 2018)

Therefore, for 1 hectare of forest land, the total weight of pruned wood will be,

0.05 ton/tree x 1100 trees/ha ***= 55 ton of pruning wood/ha***

Overijssel

According to David Mohren (Vodde, 2006), Netherlands has around 360,000 ha of forest area, which is about of 10% of the total land area in Netherlands. It further mentions that the Eastern side of Netherlands has a forest cover ranging from 10% to 20%. Since the pruning waste wood must be collected from the local regions of Overijssel. We assume that Overijssel has a forest cover of at least 10% of its total land area.

Land area of Overijssel Province = 332700 ha
Forest cover (10% of land area) = 33270 ha

Therefore, the estimated energy present in Overijssel from pruning wood

*Pruning wood / ha * Lower heating Value * Tree land cover* ***= 6.6 TWh***

<u>Mathura</u>

Similarly, for Mathura the forest land is estimated as 1592 ha and land under miscellaneous tree crops is 929 ha, therefore, the energy from pruning wood in Mathura region will be,

*Pruning wood / ha * Lower heating Value * Tree land cover =* ***0.478 TWh***

Municipal Solid Waste

The estimated energy content in MSW is 15 MJ/kg (Akkaya & Demir, 2009) with an average MSW of 2.2 kg/capita/day for European countries and 1.1 for South Asian Countries(Hoornweg & Bhada-Tata, 2012).

The province of Overijssel belonging to the European continent has a population of 1.15 million people in January 2019. Therefore, the energy potential available within the region every year from municipal solid waste is **3.86 TWh** annually.

Similarly, for Mathura, belonging to the South Asian region, has a population of 2.5 million people in year 2011. Therefore, the energy content from MSW will be **4.18 TWh**

*Energy Potential from MSW = Energy Content MJ/kg) * Average MSW (kg/capita/day) *Population* 365*

Agriculture Waste

The total available land for agriculture in Overijssel is 202,620 ha. The average crop yield and the residue data is not available on the internet. Therefore, an alternative approach was used by determining the average agriculture residue in Europe i.e. 74.89 MT/year (Iqbal, et al., 2016) with an agriculture land area of 179 million ha (Land cover and land use, 2018). From this it is determined that 418 kg of agriculture waste is generated per ha per year and has an energy content of approximately 15 MJ/kg (Gravalos, et al., 2016) . The estimate energy content is 0.35 TWh.

*Energy Content in Agriculture Waste = Agriculture Land Area Overijssel(ha) * Energy Content(MJ/kg))*
** Average agriculture residue (kg/ha)*

A similar pattern is utilized for Mathura, although, the estimation shows a large amount of agricultural waste available as the 75% of the land area is cultivated for farming. *(https://www.nabard.org/xls/uttardist/mathura%20-Dist_profile.xls)*

Organic Feedstock

The organic feedstock for Overijssel is evaluated to be 6.6PJ (Hoppe, Dijk, & Arentsen, 2011) . While for Mathura it is calculated by the cattle population *(https://www.nabard.org/xls/uttardist/mathura%20-Dist_profile.xls)* for wet biomass. It is assumed that 1 cow or buffalo produces 10 kg of wet biomass daily (Biogas, 2019), which can produce 0.062 m^3 of biogas (Kuria & Maringa, 2008). Provided that the Mathura district holds a population of 867,630 cattle (cows and buffalos) which can be used to generate biogas with 65% methane content. Therefore, the region has a green gas potential of 1.43 TWh annually.

*Energy Content from Organic Feedstock = Cattle Population * Manure Annually * 0.062 m^3/kg * Upgradation % * Energy Content of green gas (MJ/m^3)*

Solar Energy Potential

The energy potential from solar irradiation in Overijssel and Mathura is estimated by evaluating the hourly solar irradiation at one square meter for a solar panel with an assumed efficiency of 18%.

*Annual Energy Potential with a PV Panel (kWh/m^2) = ∑ [18% * Solar Irradiation (W/m^2)] /1000*

Wind Energy Potential

The wind energy potential in Overijssel and Mathura is estimated by evaluating the hourly wind speed at 10m height recorded by TU Delft for Overijssel and SoDa for Mathura at one square meter of the turbine.

Annual Wind Energy Potential (kWh/m^2) = ∑ [0.5 Hourly Air Density * (Wind Speed) ^3 (m/s)]*

Geothermal Potential

Geothermal energy for thermal comfort and electricity is another source of energy explored in the region. In 2015, the region was supplying 0.13 TWh of energy with an expected increase to 0.48 TWh in 2030 (Beursken, Reffeltrath, & Menkveld, 2016). With possible innovation and efficiency improvement, the geothermal energy potential is assumed to be 0.72 TWh

River run-off Hydro Energy Potential

River Yamuna passes through the district of Mathura and is among the largest rivers in the country in terms of length and flow rate. The river records an average flow rate of 2,950 m^3/s. The planning for river interconnection in India along with the high flow rate of the river can be utilized to install small sized run-off river hydropower plant, which can be used to provide base power to the region and an irrigation network for farms.

Appendix C: Simulation Results

C.1. Overijssel BAU Scenario Results

Input Overijssel2050BAU.txt — The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	3.97	Fixed imp/exp.	0.00
Electric heating + HP	0.22	Transportation	1.30
Electric cooling	0.00	Total	5.50

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	0.00	0.00
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.00	0.00	0.00

Wind	39	MW	0.20	TWh/year	0.00	Grid
Photo Voltaic	190	MW	0.29	TWh/year	0.00	stabili-
River Hydro	0	MW	0	TWh/year	0.00	sation
River Hydro	0	MW	0	TWh/year	0.00	share
Hydro Power	0	MW	0	TWh/year		
Geothermal/Nuclear	15	MW	0.13	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	1080		0.45		

Heatstorage: gr.2: 0 GWh gr.3 0 GWh
Fixed Boiler: gr.2:0.0 Per cent gr 0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.95
Gr.2:	0.00	0.00
Gr.3:	0.00	0.00

Regulation Strate(Technical regulation no. 1		
CEEP regulation	984567123	
Minimum Stabilisation share	0.30	
Stabilisation share of CHP	0.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	300	MW
Heat Pump maximum share	0.50	
Maximum import/export	0	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0.00	DKK/MWh
Multiplication factor	2.00	
Dependency factor	0.00	DKK/MWh pr. MW
Average Market Price	227	DKK/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencie elec.	Ther.
Hydro Pump:	0	0	0.80	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:	0.000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	5.70	2.30	0.00
Household	0.00	0.00	3.80	0.99
Industry	0.00	0.00	7.00	0.00
Various	0.00	0.00	0.00	0.00

Output

District Heating (Demand; Production; Balance):

	Distr. heating MW	Solar MW	Waste-CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW
January	0	0	19	0	0	0	0	0	0	-19
February	0	0	19	0	0	0	0	0	0	-19
March	0	0	19	0	0	0	0	0	0	-19
April	0	0	19	0	0	0	0	0	0	-19
May	0	0	19	0	0	0	0	0	0	-19
June	0	0	19	0	0	0	0	0	0	-19
July	0	0	19	0	0	0	0	0	0	-19
August	0	0	19	0	0	0	0	0	0	-19
September	0	0	19	0	0	0	0	0	0	-19
October	0	0	19	0	0	0	0	0	0	-19
November	0	0	19	0	0	0	0	0	0	-19
December	0	0	19	0	0	0	0	0	0	-19
Average	0	0	19	0	0	0	0	0	0	-19
Maximum	0	0	19	0	0	0	0	0	0	-19
Minimum	0	0	19	0	0	0	0	0	0	-19
TWh/year	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	-0.17

Electricity (Consumption; Production; Balance) and Exchange:

	Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste-CSHP MW	CHP MW	PP MW	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Payment Imp Million DKK	Payment Exp Million DKK
January	525	148	56	0	0	0	0	36	0	15	108	0	569	263	0	0	0	0	0	0
February	502	148	45	0	0	0	0	42	0	15	108	0	529	255	0	0	0	0	0	0
March	470	148	32	0	0	0	0	55	0	15	108	0	476	245	0	0	0	0	0	0
April	433	148	20	0	0	0	0	70	0	15	108	0	417	235	0	0	0	0	0	0
May	410	148	11	0	0	0	0	80	0	15	108	0	379	228	0	0	0	0	0	0
June	401	148	7	0	0	0	0	82	0	15	108	0	365	226	0	0	0	0	0	0
July	389	148	6	0	0	0	0	80	0	15	108	0	355	226	0	0	0	0	0	0
August	394	148	7	0	0	0	0	69	0	15	108	0	371	231	0	0	0	0	0	0
September	421	148	12	0	0	0	0	55	0	15	108	0	411	240	0	0	0	0	0	0
October	459	148	22	0	0	0	0	42	0	15	108	0	466	249	0	0	0	0	0	0
November	495	148	39	0	0	0	0	33	0	15	108	0	526	259	0	0	0	0	0	0
December	530	148	52	0	0	0	0	33	0	15	108	0	575	265	0	0	0	0	0	0
Average	452	148	26	0	0	0	0	56	0	15	108	0	453	244	0	0	0	0	Average price (DKK/MWh)	
Maximum	941	296	67	0	0	0	0	217	0	15	108	0	1079	297	0	0	0	0		
Minimum	203	0	0	0	0	0	0	9	0	15	108	0	290	164	0	0	0	0	235	216
TWh/year	3.97	1.30	0.22	0.00	0.00	0.00	0.00	0.50	0.00	0.13	0.95	0.00	3.98		0.00	0.00	0.00	0.00	0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Net	CO2 emission (Mt): Total	CO2 emission (Mt): Net
Coal	-	-	-	-	-	2.95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.95	0.00	2.95	1.05	1.05
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.70	-	-	5.70	0.00	5.70	1.50	1.50
N.Gas	-	-	-	-	-	2.95	-	-	-	-	-	-	-	-	-	-	-	2.30	3.80	7.00	16.05	0.00	16.05	3.29	3.29
Biomass	-	-	-	-	-	2.95	-	-	3.80	-	2.53	-	-	-	-	-	-	-	0.99	-	10.27	0.00	10.27	0.44	0.44
Renewable	-	-	-	-	-	-	1.32	-	-	-	-	-	0.20	0.29	-	-	0.33	-	-	-	2.14	0.00	2.14	0.00	0.00
H2 etc.	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-1.20	-	-	-	-	-	-	1.20	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	-	-	-	8.85	1.32	-	3.80	-	1.33	-	0.20	0.29	-	-	0.33	9.20	4.79	7.00	37.11	0.00	37.11	6.27	6.27

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Output specifications Overijssel2050BAU.txt — The EnergyPLAN model 14.1

District Heating Production — Gr.1 and Gr.2:

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Stor-age MW	Gr.2 Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

District Heating Production — Gr.3 and RES specification:

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Stor-age MW	Gr.3 Ba-lance MW	RES1 Wind MW	RES2 Photo MW	RES3 River MW	RES 4-7 MW	Total MW
January	0	0	19	0	0	0	0	0	0	-19	29	8	0	0	36
February	0	0	19	0	0	0	0	0	0	-19	27	16	0	0	42
March	0	0	19	0	0	0	0	0	0	-19	26	28	0	0	55
April	0	0	19	0	0	0	0	0	0	-19	23	47	0	0	70
May	0	0	19	0	0	0	0	0	0	-19	22	58	0	0	80
June	0	0	19	0	0	0	0	0	0	-19	20	62	0	0	82
July	0	0	19	0	0	0	0	0	0	-19	20	60	0	0	80
August	0	0	19	0	0	0	0	0	0	-19	19	50	0	0	69
September	0	0	19	0	0	0	0	0	0	-19	19	35	0	0	55
October	0	0	19	0	0	0	0	0	0	-19	22	21	0	0	42
November	0	0	19	0	0	0	0	0	0	-19	24	9	0	0	33
December	0	0	19	0	0	0	0	0	0	-19	27	6	0	0	33
Average	0	0	19	0	0	0	0	0	0	-19	23	33	0	0	56
Maximum	0	0	19	0	0	0	0	0	0	-19	39	190	0	0	217
Minimum	0	0	19	0	0	0	0	0	0	-19	5	0	0	0	9
Total for the whole year TWh/year	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00		-0.17	0.20	0.29	0.00	0.00	0.50

Own use of heat from industrial CHP 0.00 TWh/year

ANNUAL COSTS (Million DKK)	
Total Fuel ex Ngas exchange =	939
Uranium =	0
Coal =	38
FuelOil =	0
Gasoil/Diesel=	267
Petrol/JP =	267
Gas handling =	115
Biomass =	253
Food income =	0
Waste =	0
Total Ngas Exchange costs =	601
Marginal operation costs =	22
Total Electricity exchange =	0
Import =	0
Export =	0
Bottleneck =	0
Fixed imp/ex=	0
Total CO2 emission costs =	263
Total variable costs =	1825
Fixed operation costs =	0
Annual Investment costs =	432
TOTAL ANNUAL COSTS =	2257

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	0	0	422	733	262	797	2213	0	0	0	0	0	0	2213	2213	0
February	0	0	392	692	262	797	2143	0	0	0	0	0	0	2143	2143	0
March	0	0	353	597	262	797	2008	0	0	0	0	0	0	2008	2008	0
April	0	0	309	446	262	797	1813	0	0	0	0	0	0	1813	1813	0
May	0	0	280	292	262	797	1631	0	0	0	0	0	0	1631	1631	0
June	0	0	270	214	262	797	1543	0	0	0	0	0	0	1543	1543	0
July	0	0	263	173	262	797	1495	0	0	0	0	0	0	1495	1495	0
August	0	0	275	180	262	797	1513	0	0	0	0	0	0	1513	1513	0
September	0	0	305	253	262	797	1617	0	0	0	0	0	0	1617	1617	0
October	0	0	346	394	262	797	1798	0	0	0	0	0	0	1798	1798	0
November	0	0	389	555	262	797	2004	0	0	0	0	0	0	2004	2004	0
December	0	0	426	671	262	797	2156	0	0	0	0	0	0	2156	2156	0
Average	0	0	336	433	262	797	1827	0	0	0	0	0	0	1827	1827	0
Maximum	0	0	799	769	262	797	2618	0	0	0	0	0	0	2618	2618	0
Minimum	0	0	215	156	262	797	1430	0	0	0	0	0	0	1430	1430	0
Total for the whole year TWh/year	0.00	0.00	2.95	3.80	2.30	7.00	16.05	0.00	0.00	0.00	0.00	0.00	0.00	16.05	16.05	0.00

RES Share: 33.4 Percent of Primary Energy 55.1 Percent of Electricity 2.9 TWh electricity from RES

18-October-2019 [20:38]

C.2. Overijssel Energy Transition 2050

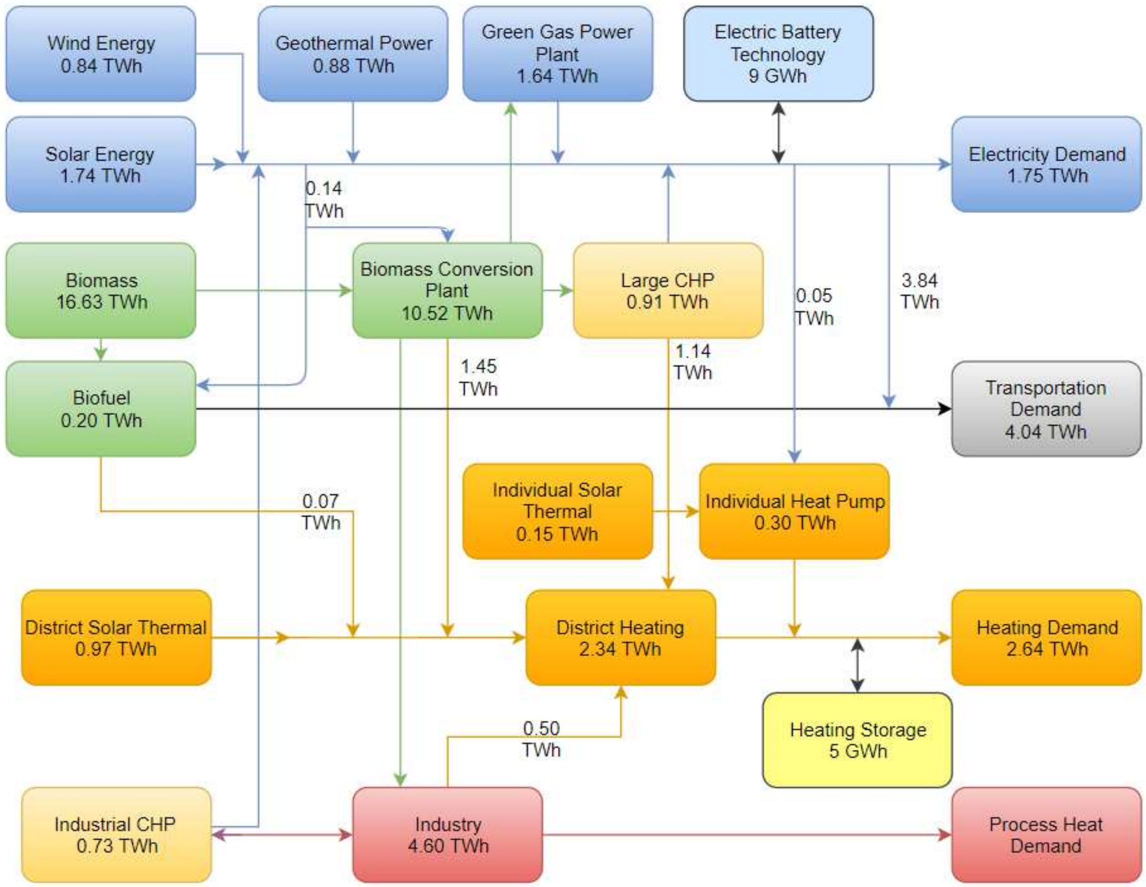

Figure 3: Energy Flow Chart for Overijssel Energy Transition Scenario 2050

Input Overijssel_2050_Energy Transition.txt — The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0.25
Fixed demand	1.89	Fixed imp/exp.	0.00
Electric heating + HP	0.05	Transportation	3.84
Electric cooling	0.00	Total	6.04

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	2.60	2.60
Solar Thermal	0.00	0.00	0.97	0.97
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.00	1.63	1.63

Wind	170 MW	0.84	TWh/year	0.00	Grid
Photo Voltaic	1000 MW	1.74	TWh/year	0.00	stabili-
Wave Power	0 MW	0	TWh/year	0.00	sation
River Hydro	0 MW	0	TWh/year	0.00	share
Hydro Power	0 MW	0	TWh/year		
Geothermal/Nuclear	100 MW	0.88	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	700	875	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	875		0.45		

Heatstorage: gr.2: 5 GWh gr.30 GWh
Fixed Boiler: gr.2:0.0 Per cent gr.0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.70	0.00
Gr.3:	0.00	0.00

Regulation Strate(Technical regulation no. 1
CEEP regulation 984532176
Minimum Stabilisation share 0.30
Stabilisation share of CHP 0.00
Minimum CHP gr 3 load 20 MW
Minimum PP 0 MW
Heat Pump maximum share 0.50
Maximum import/export 0 MW

Distr. Name : Hour_nordpool.txt
Addition factor 0.00 EUR/MWh
Multiplication factor 2.00
Dependency factor 0.00 EUR/MWh pr. MW
Average Market Price 227 EUR/MWh
Gas Storage 0 GWh
Syngas capacity 1327 MW
Biogas max to grid 135 MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficienc elec.	Ther.
Hydro Pump:	0	0	0.80	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	

CAES fuel ratio: 0.000

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	0.00	0.00	0.00
Household	0.00	0.00	0.00	0.00
Industry	0.00	0.00	4.60	0.00
Various	0.00	0.00	0.00	0.00

Output

District Heating (Demand / Production)

	Distr. heating MW	Solar MW	Waste CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Balance MW
January	686	91	229	0	389	0	0	0	0	-24
February	661	186	229	0	297	0	0	0	0	-52
March	547	308	229	0	147	0	0	0	0	-138
April	313	276	229	0	39	0	0	0	0	-231
May	127	127	229	0	25	0	0	0	0	-254
June	5	5	229	0	25	0	0	0	0	-254
July	0	0	229	0	25	0	0	0	0	-254
August	0	0	229	0	25	0	0	0	0	-254
September	6	6	229	0	25	0	0	0	0	-254
October	200	151	229	0	43	0	0	0	0	-224
November	405	110	229	0	170	0	0	0	0	-104
December	611	68	229	0	352	0	0	0	0	-38
Average	296	110	229	0	130	0	0	0	0	-174
Maximum	1202	981	229	0	875	0	0	0	0	89
Minimum	0	0	229	0	25	0	0	0	0	-254
TWh/year	2.60	0.97	2.01	0.00	1.14	0.00	0.00	0.00	0.00	-1.53

Electricity (Consumption / Production / Balance) and Exchange

	Elec. demand MW	Flex.& Transp MW	HP MW	Electrolyser MW	EH MW	Hydro Pump MW	Turbine MW	RES MW	Hydro MW	Geothermal MW	Waste CSHP MW	CHP MW	PP MW	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Payment Imp (Million EUR)	Payment Exp (Million EUR)
January	248	466	17	0	0	0	0	185	0	100	84	311	113	230	0	0	0	0	0	0
February	238	466	14	0	0	0	0	229	0	100	84	238	133	215	0	0	0	0	0	0
March	224	466	8	0	0	0	0	303	0	100	84	118	172	195	0	0	0	0	0	0
April	207	466	3	0	0	0	0	366	0	100	84	31	198	188	0	0	0	0	0	0
May	197	466	0	0	0	0	0	394	0	100	84	20	179	185	0	0	0	0	0	0
June	193	466	0	0	0	0	0	403	0	100	84	20	168	184	0	0	0	0	0	0
July	187	466	0	0	0	0	0	392	0	100	84	20	172	186	0	0	0	0	0	0
August	190	466	0	0	0	0	0	363	0	100	84	20	194	189	0	0	0	0	0	0
September	202	466	0	0	0	0	0	313	0	100	84	20	232	192	0	0	0	0	0	0
October	219	466	3	0	0	0	0	240	0	100	84	35	282	196	0	0	0	0	0	0
November	235	466	9	0	0	0	0	176	0	100	84	136	251	214	0	0	0	0	0	0
December	250	466	16	0	0	0	0	167	0	100	84	281	154	232	0	0	0	0	0	0
Average	216	466	6	0	0	0	0	294	0	100	84	104	187	200	0	0	0	0	Average price	
Maximum	433	874	46	0	0	0	0	882	0	100	84	700	821	294	0	0	0	0	(EUR/MWh)	
Minimum	105	0	0	0	0	0	0	47	0	100	84	20	0	100	0	0	0	0	223	251
TWh/year	1.89	4.09	0.05	0.00	0.00	0.00	0.00	2.59	0.00	0.88	0.73	0.91	1.64		0.00	0.00	0.00	0.00	0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp	Corrected Imp/Exp Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Oil	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
N.Gas	-	-	2.28	-	0.00	3.66	-	-	-	-	-10.52	-	-	-	-	-	-	-	-	4.60	0.02	0.00	0.02	0.00	0.00
Biomass	-	-	-	-	0.00	-	-	-	0.34	-	16.29	-	-	-	-	-	-	-	-	-	16.63	0.00	16.63	0.00	0.00
Renewable	-	-	-	-	-	-	8.78	-	-	-	-	-	0.84	1.74	-	-	1.12	-	-	-	12.49	0.00	12.49	0.00	0.00
H2 etc.	-	-	-	-	0.00	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-0.20	-	-	-	-	-	-	-	-	0.20	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	2.28	-	0.00	3.66	8.78	-	0.14	-	5.77	-	0.84	1.74	-	-	1.12	0.20	-	4.60	29.14	0.00	29.14	0.00	0.00

01-November-2019 [09:56]

Output specifications Overijssel_2050_Energy Transition.txt — The EnergyPLAN model 14.1

District Heating Production

Gr.1

	District heating MW	Solar MW	CSHP MW	DHP MW
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0
Average	0	0	0	0
Maximum	0	0	0	0
Minimum	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00

Gr.2

	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Storage MW	Balance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

Gr.3 and RES specification

	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Storage MW	Balance MW	RES1 Wind MW	RES2 Photo MW	RES3 Wave MW	RES 4-7 MW	Total MW
January	686	91	229	389	0	0	0	0	0	-24	132	54	0	0	185
February	661	186	229	297	0	0	0	0	0	-52	124	105	0	0	229
March	547	308	229	147	0	0	0	0	0	-138	121	181	0	0	303
April	313	276	229	39	0	0	0	0	0	-231	89	277	0	0	366
May	127	127	229	25	0	0	0	0	0	-254	66	328	0	0	394
June	5	5	229	25	0	0	0	0	0	-254	61	342	0	0	403
July	0	0	229	25	0	0	0	0	0	-254	59	333	0	0	392
August	0	0	229	25	0	0	0	0	0	-254	69	295	0	0	363
September	6	6	229	25	0	0	0	0	0	-254	91	222	0	0	313
October	200	151	229	43	0	0	0	0	0	-224	105	135	0	0	240
November	405	110	229	170	0	0	0	0	0	-104	112	64	0	0	176
December	611	68	229	352	0	0	0	0	0	-38	126	41	0	0	167
Average	296	110	229	130	0	0	0	0	0	-174	96	198	0	0	294
Maximum	1202	981	229	875	0	0	0	0	0	89	170	829	0	0	882
Minimum	0	0	229	25	0	0	0	0	0	-254	0	0	0	0	47
Total for the whole year TWh/year	2.60	0.97	2.01	1.14	0.00	0.00	0.00	0.00		-1.53	0.84	1.74	0.00	0.00	2.59

Own use of heat from industrial CH0.00 TWh/year

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		493
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	0	
Petrol/JP =	0	
Gas handling =	20	
Biomass =	473	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		1
Marginal operation costs =		26
Total Electricity exchange =		0
Import =	0	
Export =	0	
Bottleneck =	0	
Fixed imp/ex=	0	
Total CO2 emission costs =		0
Total variable costs =		520
Fixed operation costs =		0
Annual Investment costs =		367
TOTAL ANNUAL COSTS =		887

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	0	779	250	0	0	524	1553	135	1062	0	0	0	0	355	451	96
February	0	595	295	0	0	524	1413	135	1062	0	0	0	0	216	358	142
March	0	295	382	0	0	524	1200	135	1062	0	0	0	0	3	220	217
April	0	77	440	0	0	524	1041	135	1062	0	0	0	0	-157	136	293
May	0	50	397	0	0	524	970	135	1062	0	0	0	0	-227	74	301
June	0	50	373	0	0	524	947	135	1062	0	0	0	0	-251	49	300
July	0	50	382	0	0	524	956	135	1062	0	0	0	0	-241	60	302
August	0	50	430	0	0	524	1004	135	1062	0	0	0	0	-193	110	304
September	0	50	516	0	0	524	1090	135	1062	0	0	0	0	-107	199	307
October	0	87	626	0	0	524	1236	135	1062	0	0	0	0	39	321	282
November	0	341	559	0	0	524	1423	135	1062	0	0	0	0	225	380	155
December	0	703	342	0	0	524	1569	135	1062	0	0	0	0	372	453	81
Average	0	260	416	0	0	524	1200	135	1062	0	0	0	0	2	234	232
Maximum	0	1750	1824	0	0	524	2507	135	1062	0	0	0	0	1310	1310	624
Minimum	0	50	0	0	0	524	574	135	1062	0	0	0	0	-624	0	0
Total for the whole year TWh/year	0.00	2.28	3.66	0.00	0.00	4.60	10.54	1.19	9.33	0.00	0.00	0.00	0.00	0.02	2.06	2.03

RES Share: 99.9 Percent of Primary Energy 57.9 Percent of Electricity 3.5 TWh electricity from RES

01-November-2019 [09:56]

C.3. Mathura BAU Scenario Results

Input Mathura2050BAU.txt — The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	7.17	Fixed imp/exp.	0.00
Electric heating + HP	0.00	Transportation	0.00
Electric cooling	0.00	Total	7.17

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	0.00	0.00
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.00	0.00	0.00

Wind	0 MW	0.00	TWh/year	0.00	Grid
Photo Voltaic	145 MW	0.28	TWh/year	0.00	stabili-
Wave Power	0 MW	0	TWh/year	0.00	sation
River Hydro	0 MW	0	TWh/year	0.00	share
Hydro Power	0 MW	0	TWh/year		
Geothermal/Nuclear	0 MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	2600		0.38		

Heatstorage: gr.2: 0 GWh gr.3 0 GWh
Fixed Boiler: gr.2:0.0 Per cent gr.3:0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.00	0.00

Regulation Strategy	Technical regulation no. 1	
CEEP regulation	000000000	
Minimum Stabilisation share	0.00	
Stabilisation share of CHP	0.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0.50	
Maximum import/export	0	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0.00	EUR/MWh
Multiplication factor	2.00	
Dependency factor	0.00	EUR/MWh pr. MW
Average Market Price	227	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	163	MW

Fuel Price level:

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	0	0	0.80	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:	0.000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	5.60	4.00	0.00
Household	0.00	0.00	0.00	0.00
Industry	0.00	0.00	0.00	0.00
Various	0.00	0.00	0.00	0.00

Output

District Heating

	Demand: Distr. heating MW	Production: Solar MW	Waste-CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Electricity / Exchange

	Consumption: Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste-CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Payment Imp Million EUR	Exp Million EUR
January	823	0	0	0	0	0	0	24	0	0	0	0	799	100	0	0	0	0	0	0
February	823	0	0	0	0	0	0	28	0	0	0	0	795	100	0	0	0	0	0	0
March	809	0	0	0	0	0	0	37	0	0	0	0	772	100	0	0	0	0	0	0
April	823	0	0	0	0	0	0	40	0	0	0	0	783	100	0	0	0	0	0	0
May	806	0	0	0	0	0	0	42	0	0	0	0	763	100	0	0	0	0	0	0
June	817	0	0	0	0	0	0	39	0	0	0	0	778	100	0	0	0	0	0	0
July	811	0	0	0	0	0	0	32	0	0	0	0	779	100	0	0	0	0	0	0
August	797	0	0	0	0	0	0	29	0	0	0	0	768	100	0	0	0	0	0	0
September	808	0	0	0	0	0	0	33	0	0	0	0	775	100	0	0	0	0	0	0
October	825	0	0	0	0	0	0	30	0	0	0	0	795	100	0	0	0	0	0	0
November	819	0	0	0	0	0	0	23	0	0	0	0	796	100	0	0	0	0	0	0
December	835	0	0	0	0	0	0	21	0	0	0	0	813	100	0	0	0	0	0	0
Average	816	0	0	0	0	0	0	32	0	0	0	0	785	100	0	0	0	0	Average price	
Maximum	2600	0	0	0	0	0	0	145	0	0	0	0	2599	100	0	0	0	0	(EUR/MWh)	
Minimum	474	0	0	0	0	0	0	0	0	0	0	0	440	100	0	0	0	0	-	-
TWh/year	7.17	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	6.89		0.00	0.00	0.00	0.00	0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th	Transp	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	-	18.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.14	0.00	18.14	6.43	6.43
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.60	-	-	5.60	0.00	5.60	1.47	1.47
N.Gas	-	-	-	-	-	-	-	-	-	-	-1.43	-	-	-	-	-	-	4.00	-	0.00	2.57	0.00	2.57	0.53	0.53
Biomass	-	-	-	-	-	-	-	-	-	-	2.20	-	-	-	-	-	-	-	-	-	2.20	0.00	2.20	0.00	0.00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	-	0.28	-	-	-	-	-	-	0.28	0.00	0.28	0.00	0.00
H2 etc.	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	-	-	-	18.14	-	-	-	-	0.77	-	-	0.28	-	-	-	9.60	-	0.00	28.79	0.00	28.79	8.43	8.43

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Output specifications Mathura2050BAU.txt — The EnergyPLAN model 14.1

District Heating Production — Gr.1

	District heating MW	Solar MW	CSHP MW	DHP MW
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0
Average	0	0	0	0
Maximum	0	0	0	0
Minimum	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00

District Heating Production — Gr.2

	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

District Heating Production — Gr.3

	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

RES specification

	RES1 Wind MW	RES2 Photo MW	RES3 Wave MW	RES 4-7 MW	Total MW
January	0	24	0	0	24
February	0	28	0	0	28
March	0	37	0	0	37
April	0	40	0	0	40
May	0	42	0	0	42
June	0	39	0	0	39
July	0	32	0	0	32
August	0	29	0	0	29
September	0	33	0	0	33
October	0	30	0	0	30
November	0	23	0	0	23
December	0	21	0	0	21
Average	0	32	0	0	32
Maximum	0	145	0	0	145
Minimum	0	0	0	0	0
Total for the whole year TWh/year	0.00	0.28	0.00	0.00	0.28

Own use of heat from industrial CHP 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =	776
Uranium =	0
Coal =	232
FuelOil =	0
Gasoil/Diesel=	226
Petrol/JP =	195
Gas handling =	0
Biomass =	124
Food income =	0
Waste =	0
Total Ngas Exchange costs =	96
Marginal operation costs =	20
Total Electricity exchange =	0
Import =	0
Export =	0
Bottleneck =	0
Fixed imp/ex=	0
Total CO2 emission costs =	354
Total variable costs =	1247
Fixed operation costs =	0
Annual Investment costs =	134
TOTAL ANNUAL COSTS =	1381

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
February	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
March	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
April	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
May	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
June	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
July	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
August	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
September	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
October	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
November	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
December	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
Average	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
Maximum	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
Minimum	0	0	0	0	455	0	455	163	0	0	0	0	0	293	293	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	4.00	0.00	4.00	1.43	0.00	0.00	0.00	0.00	0.00	2.57	2.57	0.00

RES Share: 8.6 Percent of Primary Energy 3.9 Percent of Electricity 0.3 TWh electricity from RES

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C.4. Mathura Energy Transition

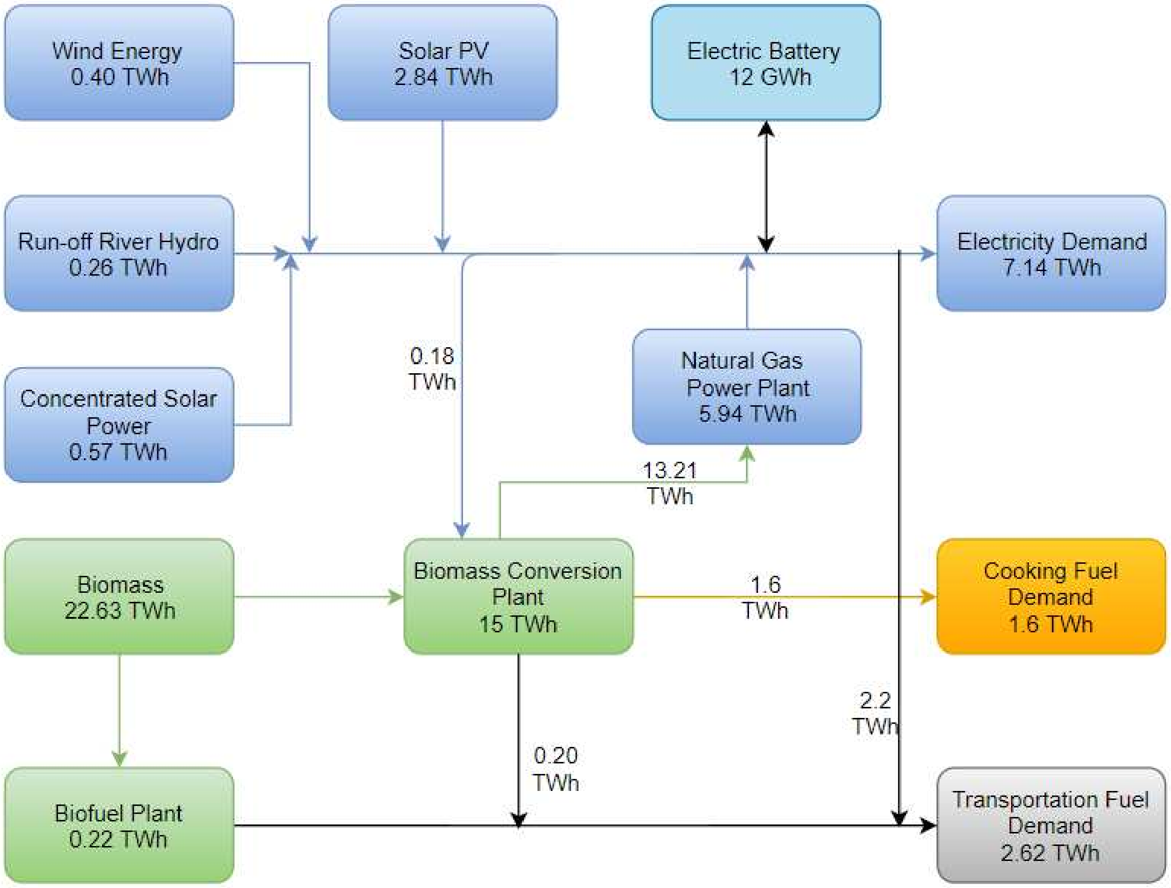

Figure 4: Energy Flow Chart for Mathura Energy Transition Scenario 2050

Input Mathura2050_Energy Transition.txt — The EnergyPLAN model 14.1

Electricity demand (TWh/year): Flexible demand 0.55
Fixed demand 6.77 Fixed imp/exp. 0.00
Electric heating + HP 0.00 Transportation 2.20
Electric cooling 0.00 Total 9.52

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	0.00	0.00
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.00	0.00	0.00

	Capacity		Production		Grid stabilisation share
Wind	150	MW	0.40	TWh/year	0.00
Photo Voltaic	1300	MW	2.84	TWh/year	0.00
Wave Power	0	MW	0	TWh/year	0.00
River Hydro	30	MW	0.92	TWh/year	0.90
Hydro Power	0	MW	0	TWh/year	
Geothermal/Nuclear	0	MW	0	TWh/year	

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	2413		0.45		

Heatstorage: gr.2: 0 GWh gr.3 0 GWh
Fixed Boiler: gr.2: 0.0 Per cent gr.3 0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.00	0.00

Regulation Strategy: Technical regulation no. 2
CEEP regulation 985432716
Minimum Stabilisation share 0.30
Stabilisation share of CHP 0.00
Minimum CHP gr 3 load 0 MW
Minimum PP 460 MW
Heat Pump maximum share 0.50
Maximum import/export 0 MW
Distr. Name : Hour_nordpool.txt
Addition factor 0.00 EUR/MWh
Multiplication factor 2.00
Dependency factor 0.00 EUR/MWh pr. MW
Average Market Price 227 EUR/MWh
Gas Storage 0 GWh
Syngas capacity 1561 MW
Biogas max to grid 381 MW

Fuel Price level:

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther
Hydro Pump:	500	4	0.80	
Hydro Turbine:	500		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:	0.000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	0.00	1.80	0.00
Household	0.00	0.00	0.00	0.00
Industry	0.00	0.00	0.00	0.00
Various	0.00	0.00	0.00	0.00

Output

District Heating (MW)

	Demand Distr. heating	Solar	Waste-CSHP	DHP	CHP	HP	ELT	Boiler	EH	Ba-lance
January	0	0	197	0	0	0	0	0	0	-197
February	0	0	197	0	0	0	0	0	0	-197
March	0	0	197	0	0	0	0	0	0	-197
April	0	0	197	0	0	0	0	0	0	-197
May	0	0	197	0	0	0	0	0	0	-197
June	0	0	197	0	0	0	0	0	0	-197
July	0	0	197	0	0	0	0	0	0	-197
August	0	0	197	0	0	0	0	0	0	-197
September	0	0	197	0	0	0	0	0	0	-197
October	0	0	197	0	0	0	0	0	0	-197
November	0	0	197	0	0	0	0	0	0	-197
December	0	0	197	0	0	0	0	0	0	-197
Average	0	0	197	0	0	0	0	0	0	-197
Maximum	0	0	197	0	0	0	0	0	0	-197
Minimum	0	0	197	0	0	0	0	0	0	-197
TWh/year	0.00	0.00	1.73	0.00	0.00	0.00	0.00	0.00	0.00	-1.73

Electricity (MW) and Exchange

	Elec. demand	Flex.& Transp	HP	Elec-trolyser	EH	Hydro Pump	Tur-bine	RES	Hy-dro	Geo-thermal	Waste-CSHP	CHP	PP	Stab-Load %	Imp	Exp	CEEP	EEP	Payment Imp (Million EUR)	Payment Exp (Million EUR)
January	777	313	0	0	0	139	100	384	0	0	0	0	748	246	0	0	0	0	0	0
February	776	313	0	0	0	153	110	434	0	0	0	0	710	240	0	0	0	0	0	0
March	764	313	0	0	0	186	134	539	0	0	0	0	625	230	0	0	0	0	0	0
April	776	313	0	0	0	190	137	569	0	0	0	0	614	226	0	0	0	0	0	0
May	760	313	0	0	0	195	140	586	0	0	0	0	587	223	0	0	0	0	0	0
June	771	313	0	0	0	193	140	576	0	0	0	0	597	220	0	0	0	0	0	0
July	766	313	0	0	0	168	121	489	0	0	0	0	659	229	0	0	0	0	0	0
August	752	313	0	0	0	153	110	441	0	0	0	0	682	235	0	0	0	0	0	0
September	762	313	0	0	0	175	126	498	0	0	0	0	650	231	0	0	0	0	0	0
October	778	313	0	0	0	164	118	445	0	0	0	0	707	240	0	0	0	0	0	0
November	773	313	0	0	0	130	94	372	0	0	0	0	754	248	0	0	0	0	0	0
December	787	313	0	0	0	113	81	348	0	0	0	0	784	251	0	0	0	0	0	0
Average	770	313	0	0	0	163	117	473	0	0	0	0	676	235	0	0	0	0	Average price	
Maximum	2409	551	0	0	0	500	500	1695	0	0	0	0	2403	333	0	0	0	0	(EUR/MWh)	
Minimum	455	0	0	0	0	0	0	31	0	0	0	0	460	100	0	0	0	0	228	219
TWh/year	6.77	2.75	0.00	0.00	0.00	1.43	1.03	4.16	0.00	0.00	0.00	0.00	5.94		0.00	0.00	0.00	0.00	0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th	Transp	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
N.Gas	-	-	-	-	-	13.21	-	-	-	-	-15.00	-	-	-	-	-	-	1.80	-	-	0.01	0.00	0.01	0.00	0.00
Biomass	-	-	-	-	-	-	-	-	-	-	22.63	-	-	-	-	-	-	-	-	-	22.63	0.00	22.63	0.00	0.00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	0.40	3.49	-	0.26	-	-	-	-	4.16	0.00	4.16	0.00	0.00
H2 etc.	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-0.22	-	-	-	-	-	-	0.22	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	-	-	-	13.21	-	-	-	-	7.41	-	0.40	3.49	-	0.26	-	2.02	-	-	26.79	0.00	26.79	0.00	0.00

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Output specifications Mathura2050_Energy Transition.txt — The EnergyPLAN model 14.1

District Heating Production

Gr.1 (MW)

	District heating	Solar	CSHP	DHP
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0
Average	0	0	0	0
Maximum	0	0	0	0
Minimum	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00

Gr.2 (MW)

	District heating	Solar	CSHP	CHP	HP	ELT	Boiler	EH	Stor-age	Ba-lance
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

Gr.3 (MW) and RES specification (MW)

	District heating	Solar	CSHP	CHP	HP	ELT	Boiler	EH	Stor-age	Ba-lance	RES1 Wind	RES2 Photo	RES3 Wave	RES 4-7	Total
January	0	0	197	0	0	0	0	0	0	-197	43	252	0	88	384
February	0	0	197	0	0	0	0	0	0	-197	46	291	0	97	434
March	0	0	197	0	0	0	0	0	0	-197	51	373	0	116	539
April	0	0	197	0	0	0	0	0	0	-197	50	398	0	122	569
May	0	0	197	0	0	0	0	0	0	-197	43	417	0	126	586
June	0	0	197	0	0	0	0	0	0	-197	62	394	0	121	576
July	0	0	197	0	0	0	0	0	0	-197	50	333	0	107	489
August	0	0	197	0	0	0	0	0	0	-197	44	298	0	99	441
September	0	0	197	0	0	0	0	0	0	-197	54	337	0	108	498
October	0	0	197	0	0	0	0	0	0	-197	34	310	0	102	445
November	0	0	197	0	0	0	0	0	0	-197	39	246	0	87	372
December	0	0	197	0	0	0	0	0	0	-197	36	230	0	83	348
Average	0	0	197	0	0	0	0	0	0	-197	46	323	0	105	473
Maximum	0	0	197	0	0	0	0	0	0	-197	150	1300	0	330	1695
Minimum	0	0	197	0	0	0	0	0	0	-197	1	0	0	30	31
TWh/year	0.00	0.00	1.73	0.00	0.00	0.00	0.00	0.00		-1.73	0.40	2.84	0.00	0.92	4.16

Own use of heat from industrial CHP 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =	767
Uranium =	0
Coal =	0
FuelOil =	0
Gasoil/Diesel=	2
Petrol/JP =	2
Gas handling =	36
Biomass =	727
Food income =	0
Waste =	0
Total Ngas Exchange costs =	0
Marginal operation costs =	22
Total Electricity exchange =	0
Import =	0
Export =	0
Bottleneck =	0
Fixed imp/ex=	0
Total CO2 emission costs =	0
Total variable costs =	788
Fixed operation costs =	0
Annual Investment costs =	418
TOTAL ANNUAL COSTS =	1207

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	0	0	1662	0	205	0	1867	381	1327	0	0	0	0	159	368	209
February	0	0	1579	0	205	0	1784	381	1327	0	0	0	0	76	293	217
March	0	0	1389	0	205	0	1594	381	1327	0	0	0	0	-114	147	261
April	0	0	1364	0	205	0	1569	381	1327	0	0	0	0	-138	130	268
May	0	0	1305	0	205	0	1510	381	1327	0	0	0	0	-197	97	294
June	0	0	1326	0	205	0	1531	381	1327	0	0	0	0	-177	114	290
July	0	0	1464	0	205	0	1669	381	1327	0	0	0	0	-38	218	256
August	0	0	1516	0	205	0	1720	381	1327	0	0	0	0	13	254	241
September	0	0	1445	0	205	0	1650	381	1327	0	0	0	0	-58	194	252
October	0	0	1571	0	205	0	1776	381	1327	0	0	0	0	68	286	218
November	0	0	1675	0	205	0	1880	381	1327	0	0	0	0	172	379	207
December	0	0	1742	0	205	0	1947	381	1327	0	0	0	0	239	445	206
Average	0	0	1503	0	205	0	1708	381	1327	0	0	0	0	1	244	243
Maximum	0	0	5340	0	205	0	5545	381	1327	0	0	0	0	3837	3837	481
Minimum	0	0	1022	0	205	0	1227	381	1327	0	0	0	0	-481	0	0
Total for the whole year TWh/year	0.00	0.00	13.21	0.00	1.80	0.00	15.01	3.35	11.65	0.00	0.00	0.00	0.00	0.01	2.14	2.14

RES Share: 100.0 Percent of Primary Energy 38.0 Percent of Electricity 4.2 TWh electricity from RES

02-November-2019 [20:46]

Declarations

Availability of data

All data generated or analysed during this study are included in this published article [and its supplementary information files].

Competing Interests

The authors declare that they have no competing interests.

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Author's contributions

SJ conducted the research and wrote the first draft of the paper

MA and AM supervised the research and the first draft of the paper

MA edited the paper into the text submitted

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Figures

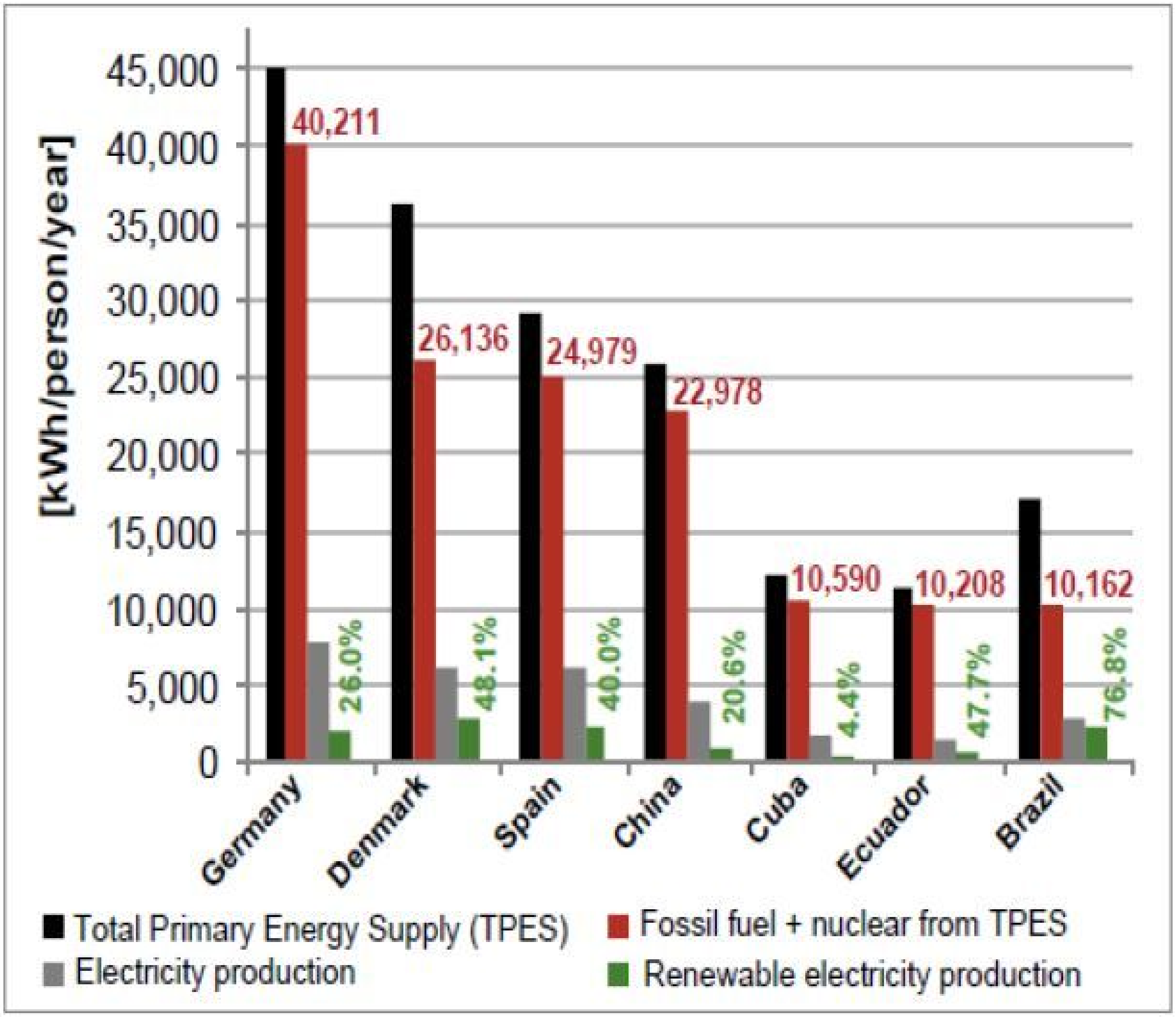

Figure 1

Primary Energy Supply per person every year in different countries signifying the differences in the GN and GS.

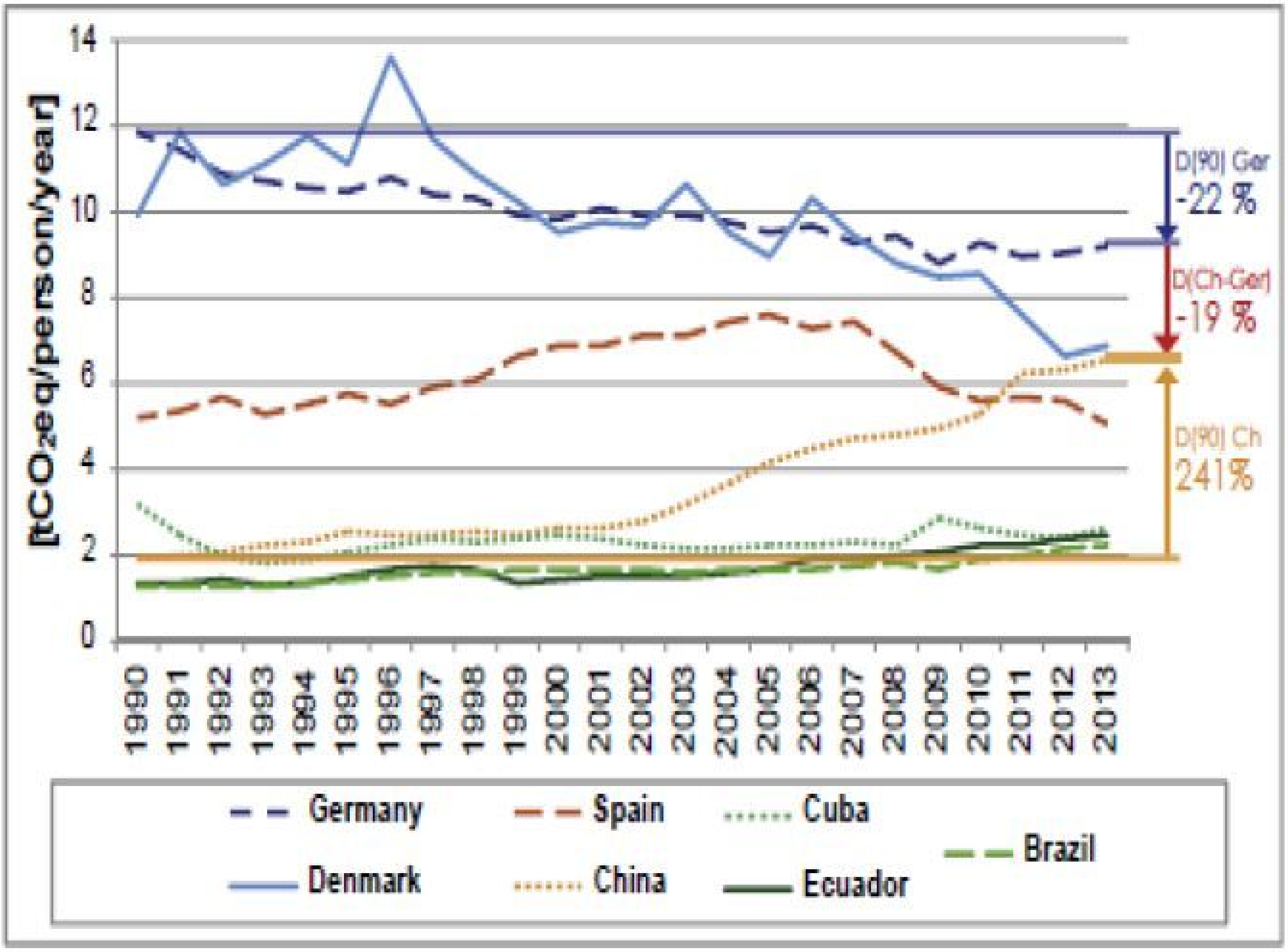

Figure 2

CO2eq emission from fuel consumption for the energy supply of globalized countries.

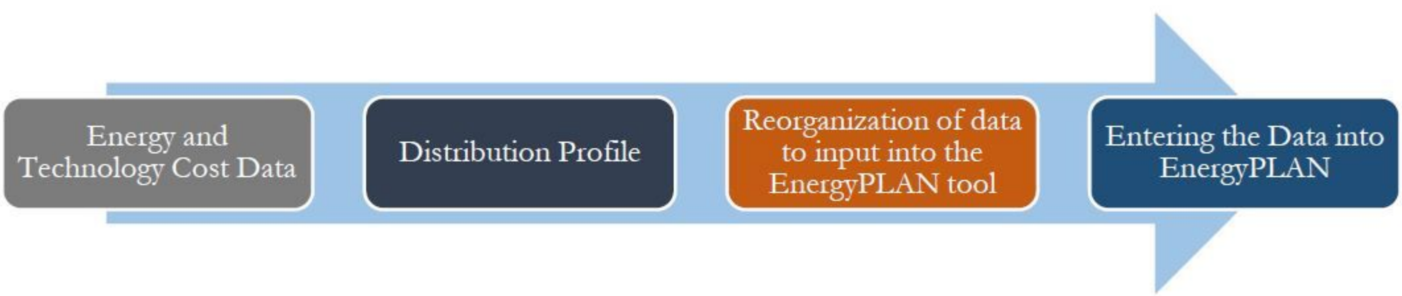

Figure 3

Process Flow for Data to be utilized in energyPLAN