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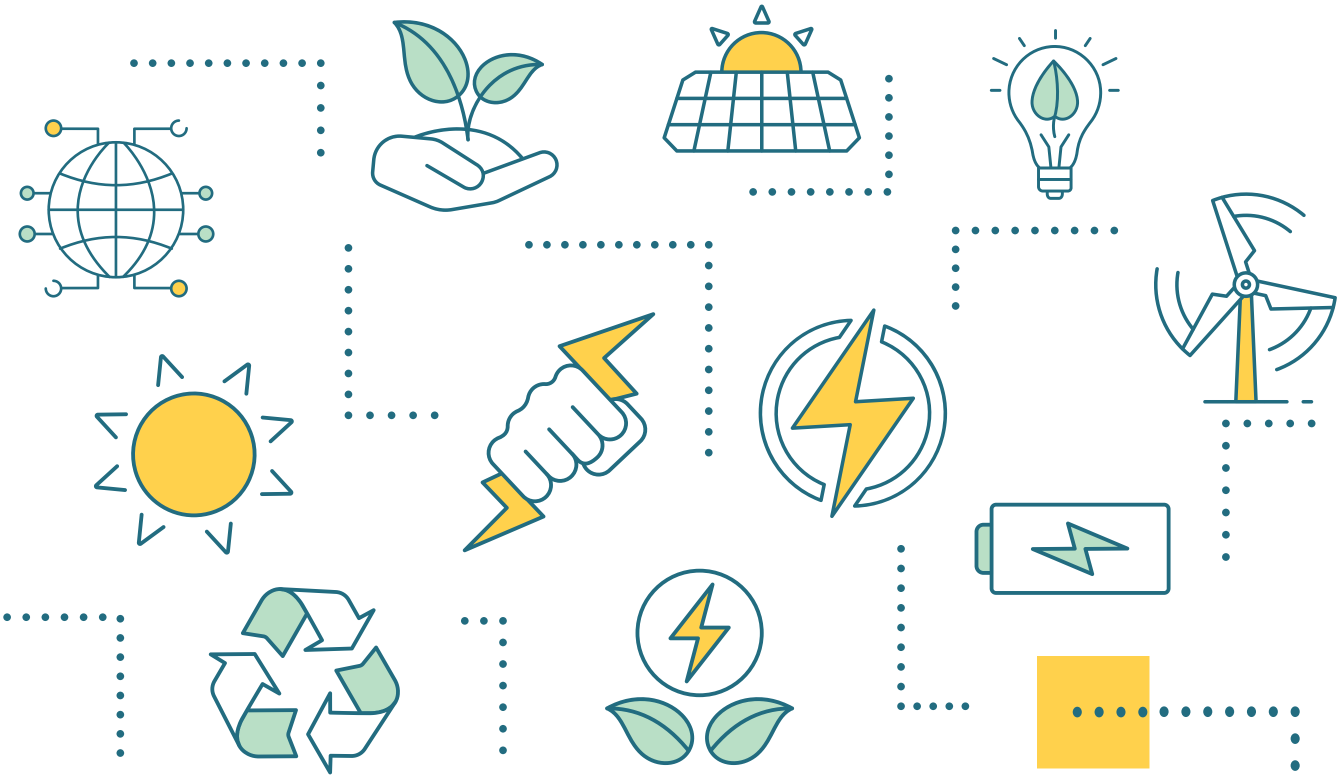
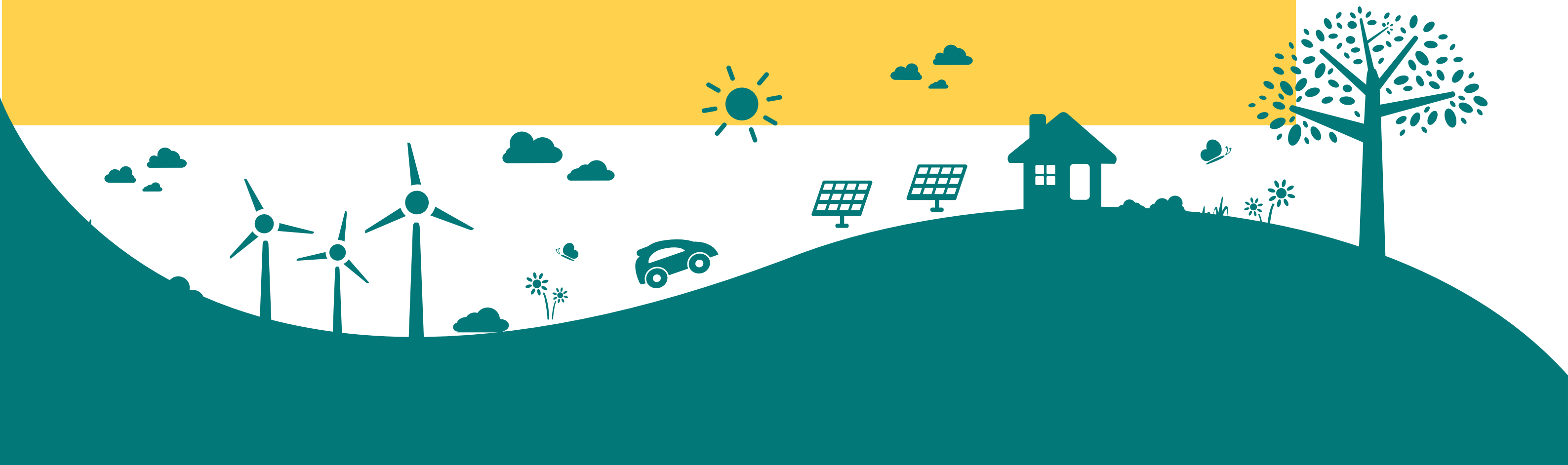


Final Energy Estimation for a Net-Zero Emissions India by 2070 via **Deep Electrification Pathway**



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About Vasudha Foundation

Vasudha Foundation is a non-profit organisation set up in 2010. We believe in the conservation of Vasudha, which in Sanskrit means the Earth, the giver of wealth, with the objective of promoting sustainable consumption of its bounties. Our mission is to promote environment-friendly, socially just and sustainable models of energy by focusing on renewable energy and energy-efficient technologies as well as sustainable lifestyle solutions. Through an innovative approach and data- driven analysis, creation of data repositories with cross-sectoral analysis, along with outreach to ensure resource conservation, we aim to help create a sustainable and inclusive future for India and Mother Earth.

About SED Fund

Stichting SED Fund is a philanthropic initiative to support the Sustainable Development Goals (SDGs) of clean air, access to energy, clean water, climate action and equity, by backing efforts of governments and civil society on clean energy transition, according to principles of sustainability, diversity and equity. We amplify impact by consolidating philanthropic resources, strengthening country level institutions and civil society groups and supporting initiatives that will have the most impact in support of these goals.

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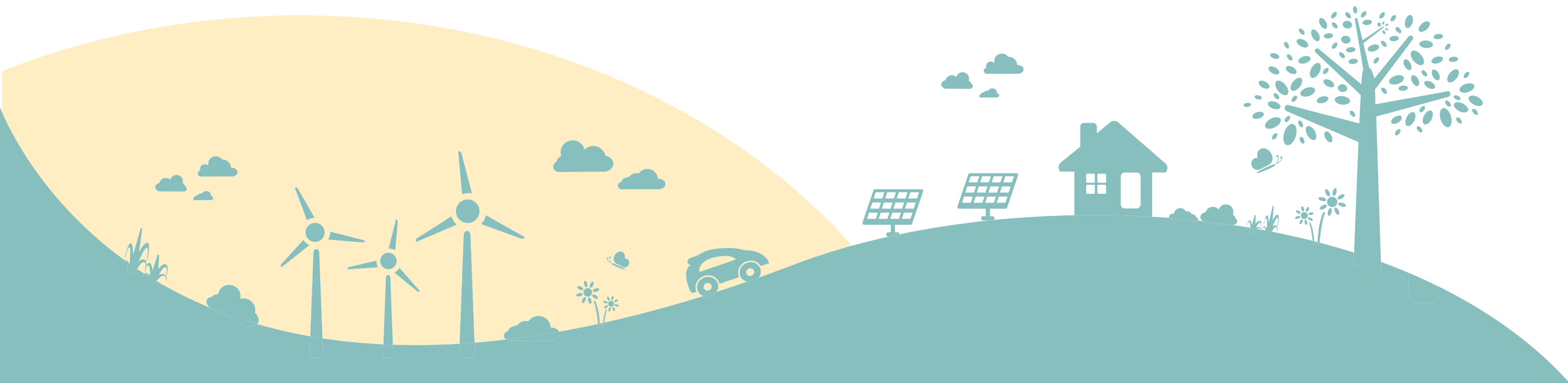

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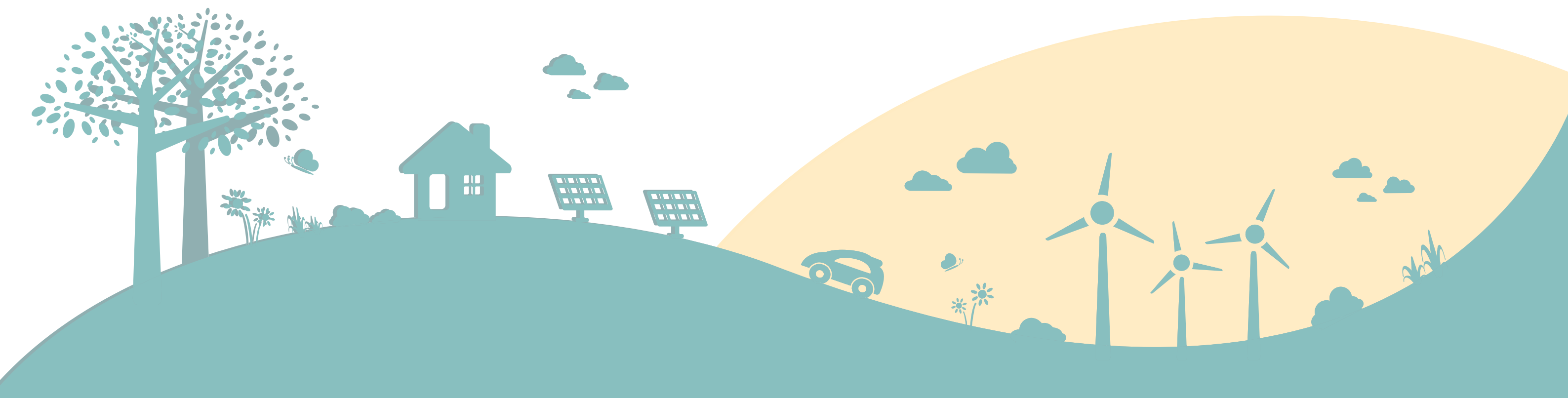


1. Introduction

Since the second half of the 20th century, significant growth in worldwide energy consumption has been observed. Findings from the International Energy Outlook, 2021, expound that with the current policy and technology improvement trends, global energy consumption is bound to increase till 2050, owing to population and economic growth[1]. The concomitant structural changes are primarily responsible for the increase in energy use, thus also translating to higher energy-related greenhouse gas emissions in the same period.

In the reality of global warming, the development of nations and subsequent energy requirements do not possess the luxury of being viewed solely as an energy-sufficiency challenge. Mitigation of carbon emissions must be prioritized parallelly. Reduction in carbon emissions is inevitably linked to a reduction in overall energy consumption, owing to the high mix of fossil fuels in present times. Higher energy efficiency and a shift to low carbon-intensive sources of energy are other significant pillars in the carbon reduction narrative. Further, from a geopolitical standpoint, securing energy supplies is critical, owing to shifting dynamics between the import-dependent and fuel-source-supplying countries in our contemporary world[2].

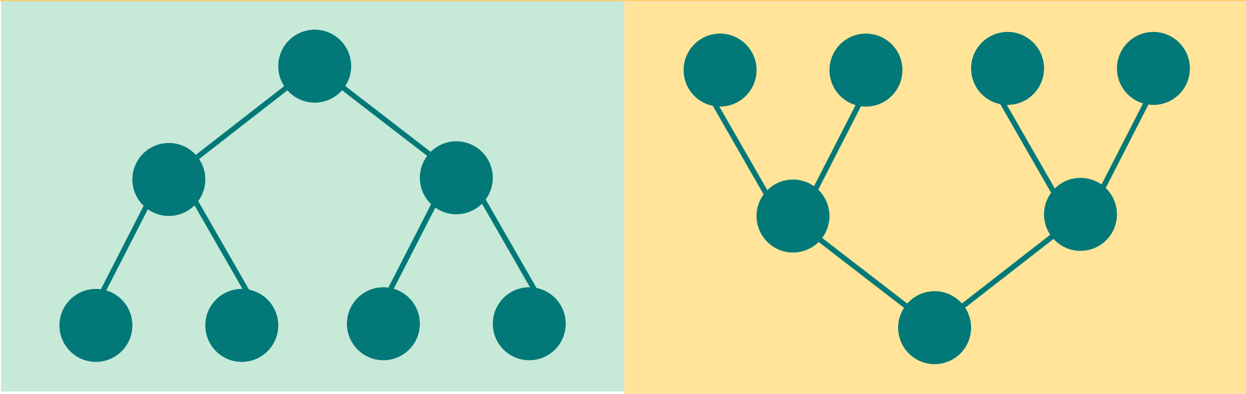
India's pathway to Net Zero must be led by a successful and just energy transition. To tackle the energy transition challenge, electrification emerges as a critical energy vector to foster a clean energy transition. Electrification brings forth a set of benefits that go well beyond GHG emission reduction. Increased influx of renewable sources in our energy mix and development of distributed energy sources improves affordability, accessibility, and security of electricity supply. Deteriorating air quality can be addressed with clean electrification. Electricity enables the digitalisation of energy uses through the integration of smart technologies and supports the development of innovative products, services, and business models, leading to a positive impact on the economy. Electrification also opens avenues to support the circular economy, thereby improving resource efficiency and leading to new jobs emerging from a well-planned just transition process.

In this paper, we examine the impact of an economy-wide deep electrification strategy on the final energy requirement for India. Multiple scenarios accounting for varying levels of direct and indirect electrification have been considered. While the majority of the energy-consuming sectors can be transitioned to direct or indirect electrification, there is a need to account for the infrastructure requirements and incorporation of digitalisation to sustain a developed Indian economy reflected by a high Human Development Index (HDI) value (≥ 0.9). Further, the adoption of circular economy practices will lead to savings across the economy, which need to be accounted for while estimating India's final energy requirement by 2070.

These estimates can serve as a reference in charting out the Net Zero pathway by contributing to energy resource planning and other critical components leading to an electrified, energy-secure, and developed India by 2070.

[1]https://www.eia.gov/outlooks/ieo/pdf/IEO2021_ReleasePresentation.pdf
[2]https://www.sciencedirect.com/science/article/pii/B9780128127469000018

2. Top-Down v/s Bottom-Up Approach



The climate science of inhibiting the rise of global average temperatures requires that a finite budget of carbon dioxide and other gases must be released into the atmosphere. For instance, meeting the 1.5°C temperature goal with a 50% probability indicates the availability of 400-800 $GtCO_2$ as the carbon budget. And remaining within this limit requires peaking of emissions before 2030 and reaching net zero at the earliest[3]. Net-zero emissions are the only strategy that can halt climate change before it reaches the stage of irreversibility. Moreover, this strategy furnishes a frame of reference to measure and compare the interventions taken by countries, all and sundry, to curb climate change[4].

Net-Zero as a strategy has several attributes of which an equitable transition to net zero and pursuit of economic opportunities holds high importance for low-to-middle-income countries. This stems from the fact that these countries have to provide a decent standard of living to their residents while achieving broader environmental objectives. To measure a decent standard of living, the final energy requirement is used as an important indicator across the world for effective planning.

As per the scientific theory, the quantification of the final energy requirement can be carried out using two approaches- Top-Down and Bottom-Up. The **top-down approach** implies examining the total energy consumption of the economy and its drivers. On the flip side, the **bottom-up approach** examines the final energy consumption at the individual level and the associated behavioural differences amongst the populace.

To select the right strategy for this paper, the objective of the research was kept at the center of decision-making. This research aims to initiate a discourse on deep electrification as a possible pathway for achieving net zero. Thus, validating the effectiveness of deep electrification strategy at the national level against other possible scenarios must be carried out. This requires a top-down approach.

Moreover, several other research papers were examined and their results and learnings were compared to further confirm the selection. It was observed that there was a huge variation in the results for papers that followed a bottom-up approach. Moreover, the assumptions on individual likings, experiences, and goals have a significant impact on final energy consumption but are difficult to quantify. Also, the size of the country creeps in biases as different geographic regions will have different needs ending up taxing the entire process of quantification.

[3]https://www.ipcc.ch/sr15/
[4]https://www.nature.com/articles/s41558-021-01245-w

3. Methodology for Final Energy Estimation

Recent reports by the Intergovernmental Panel on Climate Change (IPCC) have emphasized the critical need for the mitigation of climate change. Deep GHG emission reduction and diffusion of low-emission technologies are often challenged by financial constraints, especially in low-to-middle-income countries. India, belonging to this cohort, faces the challenge of decarbonising its emission-intensive sectors whilst balancing a steady GDP growth.

An enabling environment is critical to supporting developing economies in their mitigation efforts of climate change. Apart from increasing energy efficiency, the IPCC recommends a focus on the following- digitalisation, cross-sectoral policy linkages, and low-carbon energy sources and fuels.

Cognizant of these insights, the following identity has been derived to estimate the final energy requirement-

Final Energy (TWh/yr) =
(Direct electrification component) + (Indirect electrification component) + (Infrastructure component) – (Circular economy consideration) + (Digitalisation component)

Direct electrification component

This refers to the total amount of electricity consumed directly by the sectors as listed in Table 1. These sectors have been consolidated to cumulatively represent India's energy requirement.

Table 1: Consolidated Sectors List representing India's total energy consumption

Consolidated Sectors List			
1	Agriculture	7	Manufacturing Industries and Construction
2	Commercial	8	Mineral Industry
3	Residential	9	Chemical Industry
4	Transport	10	Metal Industry
5	Fuel Production	11	Waste
6	Public Electricity Generation	12	Agriculture, Forestry, and Other Land Use (AFOLU)

Indirect Electrification Component

Fossil fuels account for a major share of energy sources for the sectors. In the deep electrification scenario, fossil fuels have been assumed to be converted to hydrogen. Water electrolysers working on renewable sources of electricity are relied on to produce the green hydrogen required for decarbonising their respective operations. Each 'Mtoe' unit of the fossil fuel components – Coal, Oil Products, and Natural Gas has been replaced by equivalent hydrogen in 'TWh'. The method of conversion for each of these components has been explained in the succeeding sections.

Infrastructure Component

As India strives to attain higher levels of human development, it is bound to require additional infrastructure attributed to increased urbanisation, as well as support for sustaining/retrofitting the existing infrastructure. This translates to greater consumption of raw materials such as Steel and Cement. With advancements in clean technologies across energy storage and electric mobility, critical minerals such as Lithium and Silicon will also be sought. The energy requirement in relation to the operations associated with mining, processing, and end-use of these raw materials will need to be accounted for as a separate component in estimating the final energy requirement. A total of seven raw materials have been considered in this regard. The cumulative additional energy requirement arising from these critical materials has been added to the final energy estimate as the infrastructure component.

Circular Economy Consideration

Policy narratives shifting away from the linear model of extracting, manufacturing, using, and disposal of raw materials, towards a circular economy model, is set to reduce primary material consumption. This will in turn reduce the depletion of resources and environmental degradation risks, while also cutting the energy consumption and GHG emissions related to all stages of materials production[5]. In this regard, **five percent** of the infrastructure component value has been assumed to be the savings arising from the adoption of the circular economy and has been deducted from the final energy estimate.

Digitalisation Component

Digitalisation, while acknowledged as a necessary strategy in the energy transition future, does entail an increase in energy consumption. Studies indicate that the energy-increasing effects of digitalisation, triggered by economic growth, outweigh the energy-reducing effects attributed to energy efficiency measures and changes in sectoral activities[6]. Thus, an assumption of a **two percent** value of the final energy estimated has been attributed to this component.

[5]https://www.researchgate.net/publication/359793052_Analysing_the_systemic_implications_of_energy_efficiency_and_circular_economy_strategies_in_the_decarbonisation_context
[6]https://www.researchgate.net/publication/342260978_Digitalization_and_Energy_Consumption_Does_ICT_Reduce_Energy_Demand

Data Collection

Sector-wise Energy Consumption

For each of the sectors shown in Table 1, the final energy consumption was collated over four energy sources – Coal, Oil Products, Natural Gas, and Electricity. The sum of these four components represented the final energy consumption in the respective sectors. Table 2 represents the sector-wise final energy consumption (in Mtoe) for the year 2019.

Table 2: Final Energy Consumption of consolidated sectors (FY 2019) [7]

Sectors	Coal (Mtoe)	Oil (Mtoe)	Natural Gas (Mtoe)	Electricity (Mtoe)	Total (Mtoe)
Agriculture	0.00	0.81	0.00	18.35	19.16
Commercial	0.00	83.61	0.00	8.45	92.06
Residential	0.00	26.57	0.00	24.78	51.35
Transport	0.00	46.18	3.63	0.00	49.81
Fuel Production	0.09	22.84	7.10	0.00	30.03
Public Electricity Generation	315.70	0.91	10.76	0.00	327.37
Manufacturing Industries and Construction	2.79	27.40	1.15	38.82	70.15
Mineral Industry	4.86	1.64	0.00	0.00	6.50
Chemical Industry	1.10	22.64	16.95	1.92	42.61
Metal Industry	8.06	0.00	1.01	0.00	9.07
Waste	0.00	0.00	0.00	0.00	0.00
Agriculture, Forestry, and Other Land Use (AFOLU)	0.00	0.00	0.00	0.00	0.00
Total					**698.09**

Data for Infrastructure Component

Seven raw materials were identified to be included as part of the infrastructure component. Their embodied energy (in MJ/kg), world average consumption rate (in kg/capita/yr), and India-specific consumption rate (in kg/capita/yr) were collated. The difference between the world average consumption rate and the India-specific consumption rate was considered as the additional requirement. This value was in turn used to calculate the corresponding additional energy requirement. Table 3 represents the data collected to determine the additional energy requirement.

[7]https://niti.gov.in/edm/#balance

Table 3: Data for determining additional energy requirement as part of infrastructure component

Material	Embodied energy (MJ/kg)	World average Consumption rate (kg/capita/yr)	India's Consumption rate (kg/capita/yr)	Additional consumption (kg/capita/yr)
Lithium[8,9]	830	3.70	0	3.70
Silicon[10]	1656	1.42	0.93	0.49
Steel	35	225	75	150
Cement	8	500	195	305
Glass	15	9	2.5	6.5
Aluminium	200	11	2.5	8.5
Copper	71	10	0.6	9.4

Indirect Electrification: Conversion Factors for Fossil-fuels

Substitution of fossil fuels with hydrogen/direct electrification required the determination of energy equivalence factors at their respective points of use. They were obtained as follows-

i. Coal and Hydrogen

The water electrolysers were assumed to require 50 kWh to produce 1 kg of Hydrogen, operating at 75% efficiency. Typically, 10,000 MJ of coal constituted the same energy as 83.3 kg of hydrogen in accordance with their respective calorific values[11]. As per the assumption made, 83.3 kg of hydrogen would require 4167 kWh at the point of use. Thus, the following equivalence is established-

$$E_{coal} = 1.238 * E_{hydrogen}$$

ii. Oil Products and Electrification Factor

Oil products are used to power prime movers such as internal combustion (IC) engines. In the scenario where oil products are completely replaced, the same amount of energy could be derived via an electric motor [$E_{electrical}=\eta_{engine}*(E_{oil}/\eta_{electric})$]. Assuming the efficiency of a typical IC engine to be 0.3 and the efficiency of an electric motor to be 0.8, the following equivalence is established-

$$E_{electrical} = 0.375 * E_{oil}$$

iii. Natural Gas and Hydrogen

Similar to Coal, considering the calorific value for natural gas and hydrogen, for an electrolyser operating at 75% efficiency, the following equivalence is established-

$$E_{gas} = 1.286 * E_{hydrogen}$$

Table 4 represents the conversion factors for each of the fossil fuel components in electrified terms as follows-

Table 4: Electrification conversion factors for fossil fuels

Fossil fuel component	Electrification equivalence (in TWh)
1 Mtoe of Coal	17.50
1 Mtoe of Oil	31.04
1 Mtoe of Natural gas	15.02

[8]Norway value considered as value for world average owing to high penetration of battery electric vehicles.
[9]Import dependent for Lithium and hence close to nil consumption in India.
[10]Assumed 72 cells per module of 325 Wp solar panel for calculation of silicon consumption in India.
[11]https://www.currentscience.ac.in/Volumes/122/05/0517.pdf

Energy Projection Factors

i. Energy Efficiency Improvement Factor[12]

Energy efficiency measures are expected to have a larger impact in the initial years and slowly taper in their ability to reduce energy intensity. From 2020 – 2030, a 1.5 percent reduction in energy intensity per year is projected. Assuming, from 2031 – 2050, a 1.25 percent reduction in energy intensity, and from 2050 –2070, a 0.75 percent reduction in energy intensity per annum – an energy efficiency improvement factor of **1.75** is arrived at. The final energy consumption determined is divided by this factor to arrive at the final estimate.

ii. 2070 Conversion Factor

In 2070, we assume that attaining an HDI value greater than 0.9, will push India's per capita final energy consumption to 80 GJ/capita/yr. This is further elaborated in the 'S0' scenario described in the following section. Having arrived at an energy efficiency improvement factor of 1.75, we divide the per capita final energy consumption value in 2070 by this improvement factor. Given that India's current per capita final energy consumption stands at 19 GJ/capita/yr[13], we further divide the previously obtained value to arrive at the conversion factor of **2.4**. This reflects India's final energy consumption by 2070.

Description of Scenarios

Deep electrification imagined in a phased manner led to the development of four scenarios with varying levels of economy-wide electrification. A brief description of the same is shared as follows-

S0: Baseline Scenario

The baseline scenario estimates the final energy requirement for the year 2070, assuming that the current mix of energy sources remains the same. By the year India reaches its net-zero target, it is assumed that we have concomitantly strived to attain a high level of development, indicated by a high Human Development Index (HDI) value. According to insights from the Human Development Report, 2020, which expounds on the interdependence of final energy consumption and human development, the minimum final energy consumption exceeds 75 GJ/capita/yr[14] for a country. Thus, for India to achieve an HDI>0.9, a final energy consumption of 80 GJ/capita/yr is considered by 2070.

The population of India is expected to peak in 2048 at an estimated 1.6 billion[15], post which it is expected to decline. Thus, by observing the year-wise rate of population change, we assume a population of 1.5 billion by 2070. Further, we assume that 1 GJ equals $278*10^{(-9)}$ TWh, to determine the final energy consumption requirement.

The scenario also accounts for progress in energy conservation policies and improvements in energy efficiency. Thus, the final energy consumption determined is divided by the energy efficiency improvement factor of 1.75 to arrive at the final estimate.

[12]https://www.iea.org/reports/energy-efficiency-2021/executive-summary
[13]https://www.currentscience.ac.in/Volumes/122/05/0517.pdf
[14]https://hdr.undp.org/system/files/documents//hdr2020pdf.pdf
[15]https://www.thelancet.com/article/S0140-6736(20)30677-2/fulltext

S1: 50% Direct Electrification and 50% Indirect Electrification

In this scenario, a 100% electrified economy is imagined where 50% of the energy requirements are met by direct electrification and the remaining 50% is met through indirect electrification primarily via hydrogen. Referring to Table 2, in this scenario, we assume that 50% of the fossil fuel component is directly met as electricity and is hence added to the electricity-share component. The remainder of the fossil fuel component is shown in Table 5. The source-wise values across the consolidated sectors are to be subject to indirect electrification using the conversion factors mentioned in Table 4.

Table 5: Fossil Fuel consumption at 50% usage (FY 2019)

50% Fossil Fuel Usage			
Sector	Coal (Mtoe)	Oil (Mtoe)	Natural Gas (Mtoe)
Agriculture	0.00	0.40	0.00
Commercial	0.00	41.80	0.00
Residential	0.00	13.28	0.00
Transport	0.00	23.09	1.81
Fuel Production	0.05	11.42	3.55
Public Electricity Generation	157.85	0.45	5.38
Manufacturing Industries and Construction	1.40	13.70	0.57
Mineral Industry	2.43	0.82	0.00
Chemical Industry	0.55	11.32	8.48
Metal Industry	4.03	0.00	0.50
Waste	0.00	0.00	0.00
AFOLU	0.00	0.00	0.00

In addition to the direct and indirect electrification components, the scenario is also cognizant of the additional energy required to support infrastructure growth, digitalisation efforts, and the savings resulting from adopting circular economy practices. Given that the resulting final energy consumption is for the year 2019, the value is multiplied by a factor of 2.4 to arrive at the final energy requirement for the year 2070. Similar to the 'S0' scenario, this value is further divided by the energy improvements factor of 1.75 to arrive at the final energy requirement for this scenario.

S2: 75% Direct Electrification and 25% Indirect Electrification

In this scenario, a 100% electrified economy is imagined where 75% of the energy requirements are met by direct electrification and the remaining 25% is met through indirect electrification primarily via hydrogen. Referring to Table 2, in this scenario, we assume that 75% of the fossil fuel component is directly met as electricity and is hence added to the electricity-share component. The remainder of the fossil fuel component is shown in Table 6. The source-wise values across the consolidated sectors are to be subject to indirect electrification using the conversion factors mentioned in Table 4.

Table 6: Fossil Fuel consumption at 25% usage (FY 2019)

25% Fossil Fuel Usage			
Sector	Coal (Mtoe)	Oil (Mtoe)	Natural Gas (Mtoe)
Agriculture	0.00	0.20	0.00
Commercial	0.00	20.90	0.00
Residential	0.00	6.64	0.00
Transport	0.00	11.55	0.91
Fuel Production	0.02	5.71	1.77
Public Electricity Generation	78.92	0.23	2.69
Manufacturing Industries and Construction	0.70	6.85	0.29
Mineral Industry	1.21	0.41	0.00
Chemical Industry	0.27	5.66	4.24
Metal Industry	2.02	0.00	0.25
Waste	0.00	0.00	0.00
AFOLU	0.00	0.00	0.00

Similar to the 'S1' scenario, the infrastructure component, digitalisation component, and savings derived from the circular economy have been considered. The energy requirement value is multiplied by a factor of 2.4 to arrive at the final energy requirement for the year 2070. This value is further divided by the energy improvements factor of 1.75 to arrive at the final energy requirement for this scenario.

S3: 100% Direct Electrification

In this scenario, we assume that 100% of the final energy requirement is met through direct electrification. Fossil fuel usage has been terminated, and therefore there is no indirect electrification component requiring conversion to hydrogen. Across all sectors, technology is assumed to have advanced such that electricity suffices all energy needs and applications. For the year 2019, the total energy requirement has been shown in Table 7.

Table 7: Sector-wise final energy consumption (FY 2019)

Sector	Electricity (in TWh)
Agriculture	223.77
Commercial	1075.20
Residential	599.77
Transport	581.75
Fuel Production	350.76
Public Electricity Generation	3823.64
Manufacturing Industries and Construction	819.38
Mineral Industry	75.86
Chemical Industry	497.66
Metal Industry	105.93
Waste	0.00
AFOLU	0.00

Similar to 'S1' and 'S2' scenarios, the infrastructure component, digitalisation component, and savings derived from the circular economy have been considered. The energy requirement value is multiplied by a factor of 2.4 to arrive at the final energy requirement for the year 2070. This value is further divided by the energy improvements factor of 1.75 to arrive at the final energy requirement for the fully electrified scenario of all sectors in the Indian economy.

Figure 1 summarizes the attributes for the various scenarios considered as part of this paper-

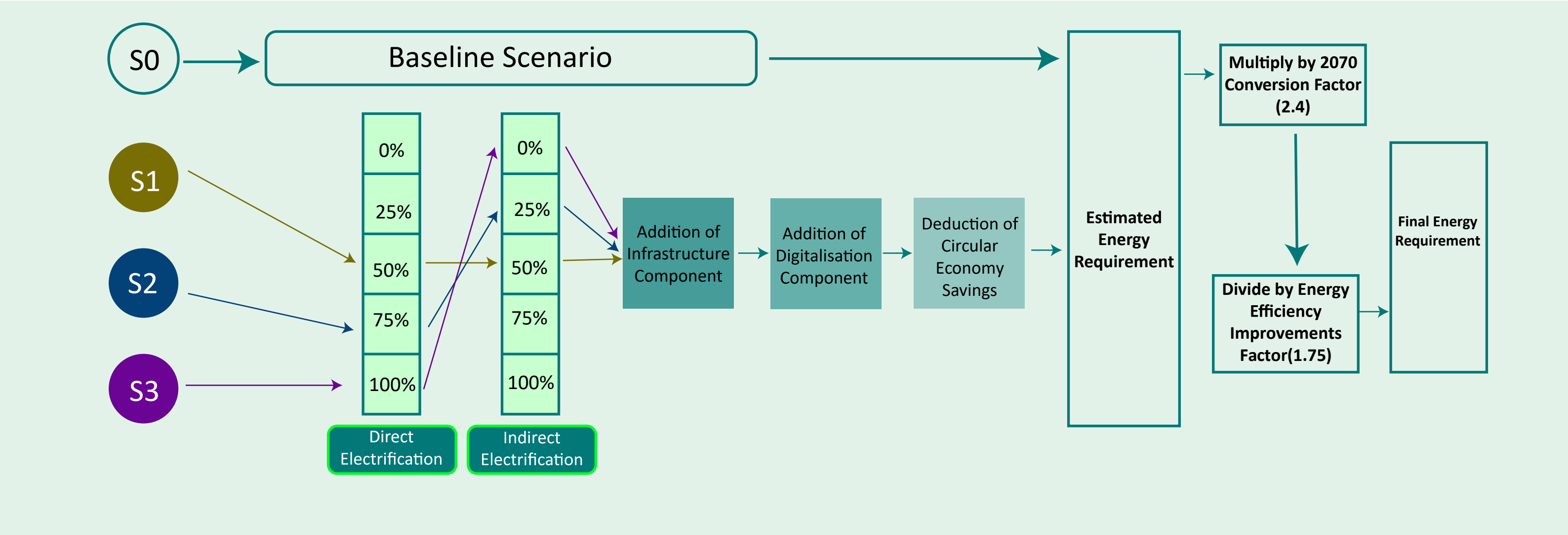


Figure 1: Scenarios for deep electrification

Final Energy Requirement Estimation

As described earlier, there are five components to the identity formulated to determine the final energy requirement. The following section traces the steps followed to arrive at the value for each of the components, leading to the final energy requirement estimation for scenarios – S1, S2, and S3.

Direct Electrification

In each of the scenarios fossil fuel usage was restricted to certain percentages. As observed in Table 2, all the energy sources were collated in common units (‘Mtoe’). Depending on the percentage of fossil fuel usage in a particular scenario, the remaining part of the requirement was assumed to be supported by direct electrification. For example, in ‘S2’, where only 25% of fossil fuels compared to 2019 levels were permitted, the remaining 75% of the energy in ‘Mtoe’ units was added directly to the electricity-share component. The sector-wise direct electrification split for all three scenarios is provided in **Annexure 1.**

Indirect Electrification

Indirect electrification sought to replace fossil fuel components with electrified counterparts. Thus, as provided in Table 4, each unit of Coal, Oil Products, and Natural Gas was multiplied by their respective conversion factors. On determining the sector-wise energy equivalents for each of the fossil fuel components, the total energy requirement for the respective scenario met through fossil fuels, was derived in ‘TWh’ terms. Subsequently, the summation of all the sectors’ respective energy requirements produced the final indirect electrification estimate. The sector-wise indirect electrification split for the ‘S1’ and ‘S2’ scenarios is provided in Annexure-1. As ‘S3’ entails, 100 percent direct electrification, there is no indirect electrification component in this scenario.

Infrastructure Component

The additional consumption required in a high development level scenario was determined by comparing the average world consumption with India's average consumption, for each of the seven raw materials in consideration. The difference in average consumption derived in 'kg/capita/yr' unit, was assumed to be the additional material consumption. Given the embodied energy[16] in 'MJ/kg', and as previously assumed, India to have a population of 1.5 billion in 2070, the additional energy requirement in (TWh/yr) was calculated using the following identity-

Additional energy requirement =
(embodied energy) * (additional consumption estimate for India) * (population of India in 2070)

On calculating the additional energy requirements for the raw materials, they cumulatively add up to **5853.18 TWh/yr.**

Circular Economy Consideration

Accounting for the savings derived from the adoption of circular economy practices, five percent of the infrastructure value was calculated. For all the scenarios, the savings from the circular economy stood at **292.66 TWh/yr.**

Digitalisation Component

Upon adding the direct electrification, indirect electrification, and infrastructure components, and deducting the savings derived from the circular economy, we arrive at an estimate in TWh/yr for all the scenarios. From this consolidated estimate, two percent of the value is calculated and attributed as the digitalisation component.

[16]It refers to the sum of the total energy used across the processing value chain from mining to transportation in order to produce the raw material for various applications.

Thus, the final energy requirement is estimated for each of the scenarios as illustrated in Figure 2.

Step 1: Direct Electrification

Calculate the percentage share from fossil fuels to be added to the electricity share component for all scenarios

Step 2: Indirect Electrification

Substitute fossil fuel energy requirements with electrification counterparts using their respective conversion factors by the concerned scenario

Step 3: Infrastructure Component

Add the additional energy requirement of all the concerned raw materials determined for the year 2070

Step 4: Savings due to Circular Economy

Calculate five percent of the infrastructure component value and deduct it from the infrastructure component value derived in Step 3 to arrive at the net additional energy requirement

Step 5: Summation of various Components before Digitalisation Consideration

Summation of direct electrification, indirect electrification, and net additional energy requirement

Step 6: Digitalisation Component

Calculate two percent of the summation arrived at in Step 5 to derive the digitalisation component value

Step 7: Final Energy Requirement (FY 2019)

Summation of values arrived at in Step 6 and Step 7

Step 8: Final Energy Requirement in 2070

Using the 2070 conversion factor (2.4), multiply it by the value derived in Step 7 to determine the final energy requirement for 2070 specific to the scenario

Step 9: Final Energy Requirement in 2070 accounting for Energy Efficiency (EE) Improvements

Using the EE improvements factor, divide the value derived in Step 8 by (1.75) to determine the final energy requirement for 2070 cognizant of EE, specific to the scenario

Figure 2 : Steps to calculate final energy requirement projections

4. Analysis and Results

Scenario-Wise Final Energy Requirement

Table 8 represents the final energy estimated for each of the scenarios in consideration. As we progress from 'S0' to 'S3', we observe a reduction in the final energy requirement concomitant to the increasing direct electrification component. A 100 percent electrified economy in India is estimated to require 19184.27 TWh/yr, where improvements in energy efficiency are accounted for.

Table 8: Final Energy Requirements for Net Zero India

Scenario	Description	Final Energy consumption (TWH/yr)
S0	Final energy requirement for India (2070)	33360.00
	Final energy accounting after EE improvements	19062.86
S1	Final energy requirement for India (2070)	41619.34
	Final energy accounting after EE improvements	23782.48
S2	Final energy requirement for India (2070)	37595.90
	Final energy accounting after EE improvements	21483.37
S3	Final energy requirement for India (2070)	33572.47
	Final energy accounting after EE improvements	19184.27

Sensitivity Analysis

Varying Digitalisation Component

In this study, we have assumed **two percent** of the final energy estimate to be attributed as the additional energy consumption attributed to digitalisation measures across the economy. Accounting for an alternate scenario where the energy efficiency measures result in energy conservation that exceeds our current expectation, the digitalisation component will further decrease its quantum of energy consumption. Thus, to present a comparison, we have assumed an alternate scenario where the digitalisation component accounts for only **one percent** of the final energy estimate. Figure 3, represents the variation in final energy estimates across the various scenarios in consideration for this study. As expected, the 'S3' scenario when accounted for EE improvements yields the lowest final energy requirement for an electrified Indian economy by 2070.

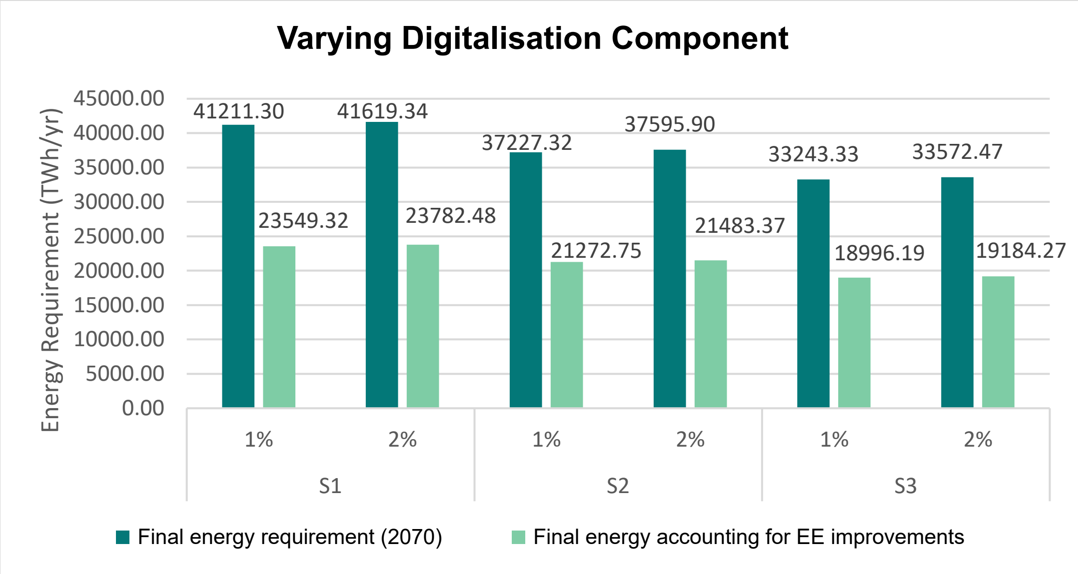


Figure 3: Impact of varying digitalisation components on final energy requirement

Varying Circular Economy Savings

In this study, the adoption of circular economy practices is assumed to result in energy savings, and a **five percent** value of the infrastructure component has been assumed to be the resultant savings, which was deducted from the final energy estimate. Assuming that advancements in circular economy practices result in improved net savings, the final energy estimate is bound to further see a decrease. Thus, to present a comparison, we have assumed an alternate scenario where the savings due to the circular economy accounts for **ten percent** of the infrastructure component and is subsequently deducted from the final energy estimate. Figure 4 represents the variation in final energy estimates corresponding to the savings component assumed.

The 'S3' scenario accounting for EE improvements and ten percent savings in the infrastructure component attributed to a circular economy, results in the lowest estimate of 18782.91 TWh/yr.

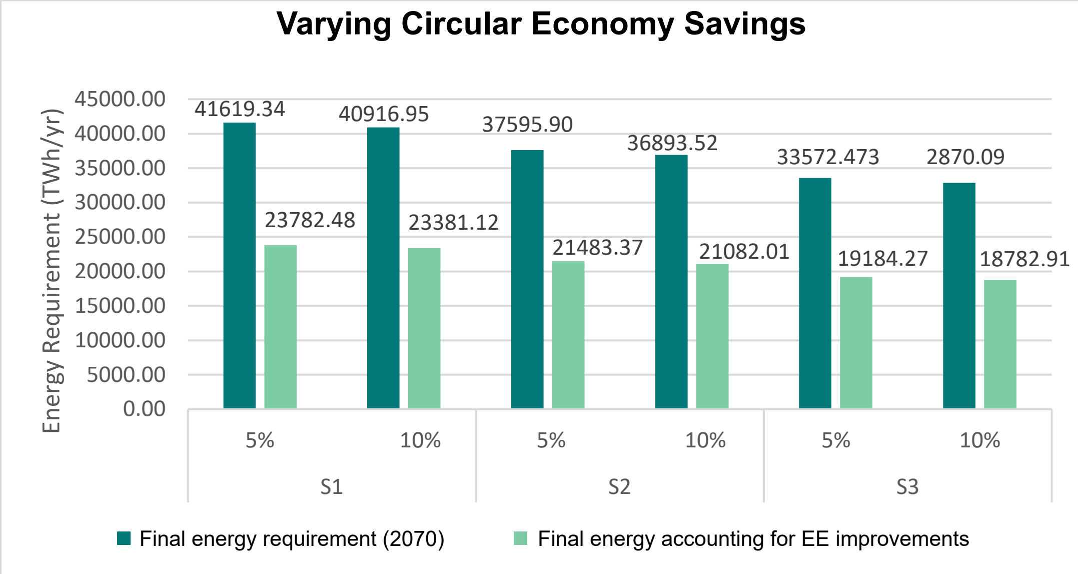


Figure 4: Impact of varying circular economy savings component on final energy requirement

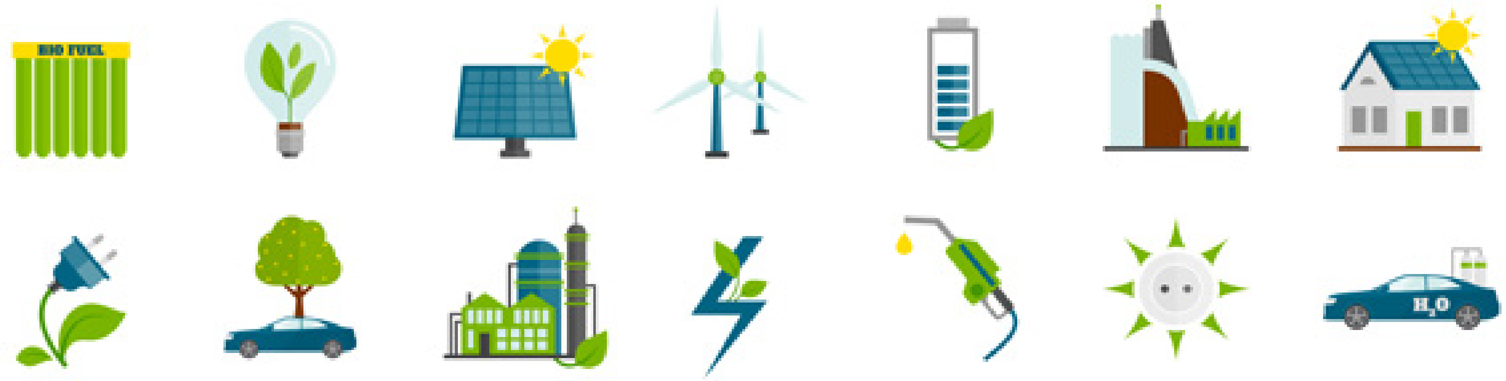
Combined Impact:

Variations in the digitalisation component yield the lowest final energy estimate when assuming a **one percent** attribute. Correspondingly, the lowest estimate while varying the circular economy savings component is achieved assuming an attribute of **ten percent**. Table 9, represents the energy estimate for the best-case estimate across all the scenarios. 'S3' scenario, when accounted for EE improvements results in the lowest final energy estimate of 18,590.81 TWh/yr.

Table 9: Final energy estimates for best-case attributes to digitalisation and circular economy component

	S1 (Results in TWh/yr)	**S2** (Results in TWh/yr)	**S3** (Results in TWh/yr)
Circular economy savings at 10%	585.00	585.00	585.00
Net additional energy requirement	5267.87	5267.87	5267.87
Electricity requirement per year	16708.70	15065.14	13421.59
Digitalisation at 1%	167.09	150.65	134.22
Final energy requirement per year	16875.79	15215.80	13555.80
Final energy requirement (2070)	40501.90	36517.91	32533.92
Final Energy accounting after EE improvements	23143.94	20867.38	18590.81

5. Conclusion



In an electrified India, where deep electrification of all the energy-consuming sectors has been successfully achieved, we observe that the business-as-usual estimations for final energy requirements by 2070 lie between

33,360 TWh/yr and **41,620** TWh/yr

Accounting for improvements in energy efficiency, the estimate is expected to lie in a lower range between

19,063 TWh/yr and **23,783** TWh/yr

Further, advancements in technology leading to lower digitalisation expenditure, and improved circular economy practices, yield a range of estimates between

18,591 TWh/yr and **23,144** TWh/yr

Thus, **India's final energy requirement by 2070 is largely dependent on the technological progress achieved, the rate of climbing energy efficiency, and robust policy interventions.** In line with energy conservation policies, we observe that a fully electrified economy can lower its final energy requirements below the baseline estimate, thus positing deep electrification as a serious contender in leading India's Net Zero pathway.

Annexure-1

1.1 'S1' direct electrification component

Sector	Electricity requirement (in Mtoe)	Electricity requirement (in TWh)
Agriculture	18.75	219.04
Commercial	50.25	586.92
Residential	38.07	444.62
Transport	24.90	290.88
Fuel Production	15.02	175.38
Public Electricity Generation	163.68	1911.82
Manufacturing Industries and Construction	54.48	636.37
Mineral Industry	3.25	37.93
Chemical Industry	22.26	260.05
Metal Industry	4.53	52.96
Waste	0.00	0.00
AFOLU	0.00	0.00
Total	**395.20**	**4615.97**

1.2 'S2' direct electrification component

Sector	Electricity requirement (in Mtoe)	Electricity requirement (in TWh)
Agriculture	18.96	221.40
Commercial	71.15	831.06
Residential	44.71	522.19
Transport	37.36	436.31
Fuel Production	22.52	263.07
Public Electricity Generation	245.52	2867.73
Manufacturing Industries and Construction	62.32	727.88
Mineral Industry	4.87	56.90
Chemical Industry	32.44	378.86
Metal Industry	6.80	79.45
Waste	0.00	0.00
AFOLU	0.00	0.00
Total	**546.65**	**6384.85**

1.3 ‘S3’ direct electrification component

Sector	Electricity requirement (in Mtoe)	Electricity requirement (in TWh)
Agriculture	19.16	223.77
Commercial	92.05	1075.20
Residential	51.35	599.77
Transport	49.81	581.75
Fuel Production	30.03	350.76
Public Electricity Generation	327.37	3823.64
Manufacturing Industries and Construction	70.15	819.38
Mineral Industry	6.50	75.86
Chemical Industry	42.61	497.66
Metal Industry	9.07	105.93
Waste	0.00	0.00
AFOLU	0.00	0.00
Total	**698.09**	**8153.72**

1.4 ‘S1’ Indirect electrification component

Sector	Coal (TWh)	Oil (TWh)	Natural Gas (TWh)	Total (in TWh)
Agriculture	0.00	12.56	0.00	12.56
Commercial	0.00	1297.62	0.00	1297.62
Residential	0.00	412.32	0.00	412.32
Transport	0.00	716.72	27.24	743.96
Fuel Production	0.80	354.48	53.31	408.59
Public Electricity Generation	2762.36	14.11	80.80	2857.27
Manufacturing Industries and Construction	24.45	425.21	8.60	458.26
Mineral Industry	42.49	25.45	0.00	67.94
Chemical Industry	9.62	351.34	127.30	488.26
Metal Industry	70.54	0.00	7.57	78.11
Waste	0.00	0.00	0.00	0.00
AFOLU	0.00	0.00	0.00	0.00
Total				**6824.87**

1.5‘S2’ Indirect electrification component

Sector	**Coal (TWh)**	**Oil (TWh)**	**Natural Gas (TWh)**	**Total (in TWh)**
Agriculture	0.00	6.28	0.00	6.28
Commercial	0.00	648.81	0.00	648.81
Residential	0.00	206.16	0.00	206.16
Transport	0.00	358.36	13.62	371.98
Fuel Production	0.40	177.24	26.66	204.30
Public Electricity Generation	1381.18	7.06	40.40	1428.64
Manufacturing Industries and Construction	12.22	212.60	4.30	229.13
Mineral Industry	21.24	12.72	0.00	33.97
Chemical Industry	4.81	175.67	63.65	244.13
Metal Industry	35.27	0.00	3.78	39.05
Waste	0.00	0.00	0.00	0.00
AFOLU	0.00	0.00	0.00	0.00
Total				**3412.43**

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