IoT-aided Smart City for Energy Efficiency

Submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

in

Computer Science and Engineering

By

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Under the guidance of

Prof. Umadevi K S

SCOPE

VIT, Vellore

December, 2021

DECLARATION

I hereby declare that the thesis entitled "IoT-aided Smart City for Energy Efficiency" submitted by me, for the award of the degree of Bachelor *of Technology in CSE* to VIT is a record of bonafide work carried out by me under the supervision of **Prof. Umadevi K S**.

I further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

Place: Vellore

Date:

Signature of the Candidate

<u>CERTIFICATE</u>

This is to certify that the thesis entitled "IoT-aided Smart City for Energy Efficiency" submitted by Mohd Umar (18BCE0196), Umang Mathur (18BCE0746) and Singh Aman Vinay Kumar (18BCE0725) SCOPE, VIT, for the award of the degree of Bachelor of Technology in CSE, is a record of bonafide work carried out by him / her under my supervision during the period, 01.07.2021 to 30.11.2021, as per the VIT code of academic and research ethics.

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Place: Vellore

Date: **Signature of the Guide**

Internal Examiner **External Examiner**

Head of the Department

Computer Science and Engineering

ACKNOWLEDGEMENTS

We would like to thank VIT, Vellore for giving us the opportunity to work towards a greater social good and to be able to bring out our ideas to fruition. We would also like to express our sincere gratitude to our subject teacher, Prof. Umadevi K S for being our tutor and guide in the process.

Submitted for CSE3999

DATE:

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Abbreviations

UNDP: United Nations Development Program

IoT: Internet of Things

IEA: International Energy Agency

RFID: Radio Frequency Identification

ISA: International Solar Alliance

USD: United States Dollar

INR: Indian Rupee

MQTT: MQ Telemetry Transport

Abstract: *One of the greatest challenges today is our pattern of energy consumption and supply that involves a massive amount of emission of greenhouse gases and heat despite numerous conventions like the Kyoto, Montreal and Paris accords. Through this project we aim to analyze current energy consumption and develop a computer-aided benchmark and baseline for energy efficiency of buildings in cities. Further, we propose an IoT-aided infrastructure for an energy efficient future through example visualizations of potential energy efficient office blocks (which may be extended to buildings or even city blocks). The main motivation behind this project is to research and understand our world's current energy-related issues and further aid in implementing the United Nations Development Programme goals of a better future.*

I. Introduction

1.1. Objective

The 17 UNDP goals enlist the strong need for humanity to move towards safer, equitable and sustainable living standards. One of the greatest challenges in the same is the pattern of energy consumption and supply that involves a massive amount of emission of greenhouse gases and heat despite numerous conventions like the Kyoto, Montreal and Paris accords.

Cities alone produce 60-80 percent of the total greenhouse gas emissions globally and are responsible for the consumption of 80 percent of the global energy. This involves heating, ventilation, air conditioning, lighting, and major appliances. And as per an independent IBM research, 70% of world population shall live in cities by 2050 while 50% of global energy shall be consumed by the building in the city alone.

City officials and governments across the planet have struggled so far to effectively analyse, visualize, and translate data from thousands of buildings into policy and program recommendations – partly due to the issue in logistics, partially due to economic and political constraints. Computers, however, provide not only with tools that can be used to benchmark consumption and supply but also to develop models that can compare and demonstrate impacts of energy-efficiency based improvements on the same.

II. Aim

This project thus aims to study modern patterns of energy consumption and related costs and to further suggest IOT based solutions to improvise upon the same.

- Using models of machine learning and statistics to visualize energy consumption of buildings in an urban setup; and
- Developing a computer-aided benchmark and baseline for energy efficiency of buildings in cities.

III. Literature Survey

1. "The 2018 International Energy Efficiency Scorecard", Fernando Castro-Alvarez, Shruti Vaidyanathan, Hannah Bastian,

and Jen King, ACEEE, 2018

Description: This research examines the efficiency policies and performance of 25 of the world's top energy-consuming countries. Each country's efficiency efforts were evaluated and scored using 36 policy and performance metrics spread over four categories: buildings, industry, transportation, and overall national energy efficiency progress. It provides an in-depth look into each country's energy efficiency policies and compares them to their actual energy efficiency, clearly highlighting the need for better strategies. For example, India was given an overall score of 50.5 out of a total 100 possible points.

Topics Covered:

- Analysis of energy efficiency policies of 25 countries
- Evaluation of the change in energy efficiency in recent years for each country
- Evaluation of energy efficiency of countries based on 36 different metrics across four categories:
    - Buildings: Residential, Commercial, Appliances and Equipment standards, etc.
    - Industry: Highlighting need for mandatory Energy Audits, CHP Policies, Standards for Motors, Investment in R&D

- Transportation: Passenger Vehicle fuel economy standards, Use of Public Transport, Fuel Efficiency for Freight and Heavy-Duty vehicles
- Overall Progress: National Policies, Investment into R&D, Tax Incentives and Loan Programs

Use in Project: Provides an in-depth overview of the state of energy efficiency and resource management for various countries and highlights the need for better strategies for saving energy and our non-renewable energy sources.

2. "Improving Building Energy Efficiency in India: State-level Analysis of Building Energy Efficiency Policies", Sha Yu *et al*, Energy Policy, Volume 110, 2017

Description: This paper analyzes the energy efficiency situation in India specifically. India is expected to add 40 billion m^2 of new buildings till 2050. Buildings are responsible for one third of India's total energy consumption today and building energy use is expected to continue growing driven by rapid income and population growth. The implementation of the Energy Conservation Building Code (ECBC) is one of the measures to improve building energy efficiency. Using the Global Change Assessment Model, this study assesses growth in the buildings sector and impacts of building energy policies in Gujarat, which would help the state adopt ECBC and expand building energy efficiency programs. Without building energy policies, building energy use in Gujarat would grow by 15 times in commercial buildings and 4 times in urban residential buildings between 2010 and 2050.

Topics Covered:

- A comprehensive overview of building energy policies in India
- An integrated assessment model for energy efficiency
- Energy and economic savings of ECBC in comparison with other building energy policies
- Strategies to improve ECBC implementation
- Implications for future policy development

Use in Project: Provides a more detailed look into energy efficiency policies (primarily for buildings) in the context of India.

3. "IoT for the Failure of Climate-Change Mitigation and Adaptation and IIoT as a Future Solution", Nesma Abd El-Mawla,

Mahmoud Badawy, Hesham Arafat, World Journal of Environmental Engineering, 2019

Description: The paper presents the idea that the Internet of Things (IoT) offers several resources and variant tools that help businesses and governments reduce the bad effect of human activity on Earth. The Internet of Things can help decarbonizes our energy system, provide modern energy systems to every human being, manage our infrastructure, and allow us to adapt to and address climate change. IoT advancements can allow companies, governments, and consumers to reverse climate change without the need of sacrificing their convenience. It shows that information and communication technologies (ICT) could help cut up to 63.5 Gtonnes of Greenhouse Gas (GHG) emissions by 2030. The paper also presents specific use cases of IoT in various fields such as Agriculture, Transportation, Waste Management and Smart Cities.

Topics Covered:

- A report and analysis of the current failure of climate change mitigation and adaptation (2019)
- Presenting the idea of utilizing IoT in the fight against climate change
- Use cases of IoT in Agriculture, Building Automation, Smart Cities, Transportation, Waste Management
- The Industrial Internet of Things (IIoT) and its challenges

Use in Project: Getting an initial idea of real-time use cases of IoT technologies.

4. "A review on Internet of Things solutions for intelligent energy control in buildings for smart city applications", Iman Khajenasiria, Abouzar Estebsarib, Marian Verhelsta, Georges Gielena, Energy Procedia 111, 2017

Description: A smart city exploits sustainable information and communication technologies to improve the quality and the performance of urban services for citizens and government, while reducing resources consumption. Intelligent energy control in buildings is an important aspect in this. The Internet of Things can provide a solution. It aims to connect numerous heterogeneous devices through the internet, for which it needs a flexible layered architecture where the things, the people and the cloud services are combined to facilitate an application task. Such a flexible IoT hierarchical architecture model is introduced in this paper with an overview of each key component for intelligent energy control in buildings for smart cities.

Topics Covered:

- Applications of IoT in the specific context of smart cities
- IoT Architectures and the IoT Software Platform
- IoT Hardware Enabling Technologies
- IoT Design Challenges

Use in Project: This paper provides a thorough ***technical overview*** of IoT technologies. It covers both hardware infrastructures, softwares and various protocols such as WiFi, IEEE 802.15.4, Bluetooth, Z-Wave, LTE-advanced, ZigBee, IrDA, etc. We thus obtain a clear view of the advantages and challenges of various IoT implementations and are thus able to select the best model for our project.

5. "Internet-of-Things-Based Optimal Smart City Energy Management Considering Shiftable Loads and Energy Storage", Hêriş Golpîra, Salah Bahramara, Journal of Cleaner Production, 2020

Description: Formulating a novel mixed integer linear programing problem, this paper introduces an optimal Internet-of-Things-based Energy Management (EM) framework for general distribution networks in Smart Cities (SCs), in the presence of shiftable loads. The system's decisions are optimally shared between its two main designed layers; a "core cloud" and the "edge clouds". The EM of a Microgrid (MG), covered by an edge cloud, is directly done by its operator and the Distributor System Operator (DSO) is responsible for optimising the EM of the core cloud. Changing the load consumption pattern, based on market energy prices, for the edge clouds and their peak load hours, the framework results in decreasing the total operation cost of the edge clouds. Using the optimal trading power of the MGs aggregators as the in put parameters of the core cloud optimisation problem, the DSO optimises the network's total operation cost addressing the optimal scheduling of the energy storages. The energy storages are charged in low energy prices through the purchasing power from the market and discharged in high energy prices to meet the demand of the network and to satisfy the energy required by the edge clouds. As a result, the shiftable loads and the energy storages are used by the DSO and the MGs to meet the energy balance with the minimum cost.

Topics Covered:

- Microgrids
- Core clouds and edge clouds
- Distributor System Operator
- Optimal Scheduling problem

Use in Project: This paper analyzes IoT-based smart cities from a mathematical perspective and proposes an energy management framework to optimize operational costs and address the optimal scheduling of energy storages. This existing solution is used as a reference infer ideas from in our project.

6. "The Network Architecture Designed for an Adaptable IoT-based Smart Office Solution", Karol FURDIK, Gabriel LUKAC, Tomas SABOL, Peter KOSTEL, International Journal of Computer Networks and Communications Security, 2013

Description: This paper introduces the concept of the Smart Office, as an application type belonging to the Internet of Things (IoT) domain, typically covers features supporting intelligent behavior of work environment, namely office rooms. A network of dedicated sensors, actuators, and various specialized devices is employed to adjust the settings of temperature, light intensity, humidity, vibrations, noise level, and other in-room environment parameters in accordance with preferences of office employees. In line with the IoT principles, the networked sensors and devices are acting as autonomous and adaptable entities that exchange produced and consumed data by means of Internetlike protocols, provide services embedded directly in the devices, update their inner status and generate events as responses to changes in the outside context.

Topics Covered:

- Key requirements for a Smart Office
- Infrastructure that allows flexibility and scalability while being energy efficient
- IoT devices that respond and adapt to user preferences
- IoT-enabling Middleware
- Novel architecture of IoT Smart Office Solution

Use in Project: The main idea for our project is drawn from this research. The paper provides all the possible requirements for a successful and energy efficient IoT-based Smart Office solution which must be kept in mind when designing a visualization such as the one proposed in our project.

7. "*A Systematic Survey on the use of Fuzzy Graph Structures in India'sSmart City Development"* by B. Angel, and D.Angel, IEEE, 2021.

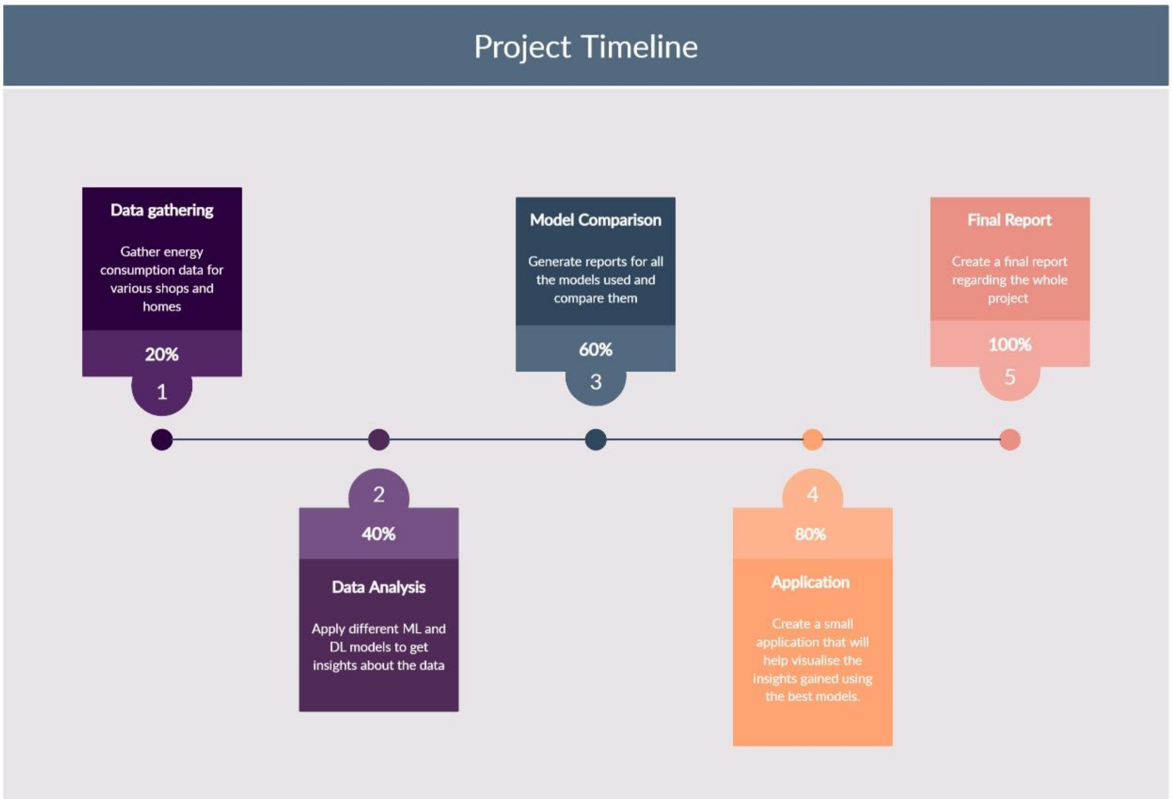
Description: The authors have carried out a survey on the current model of smart cities in India, taking in account various parameters like welfare housing, water supply and sanitation. This data is then mapped to a graph and using fuzzy logic and graph theory, the sustainability of such a model is predicted.

8. *"IoT Smart City Architectures: an Analytical Evaluation",* by Mahdi Fahmideh et al., IEEE, 2018.
Description: The authors have proposed a multi-dimensional analytical framework to evaluate various criterion for a smart city architecture. A total of 34 metrics have been proposed and finally these metrics were compared against ISO(architecture evaluation), Cisco(for network), OGC(functional requirement standards) and IEC standard. This evaluation was carried out over 22 metrics like data, intelligence and security.

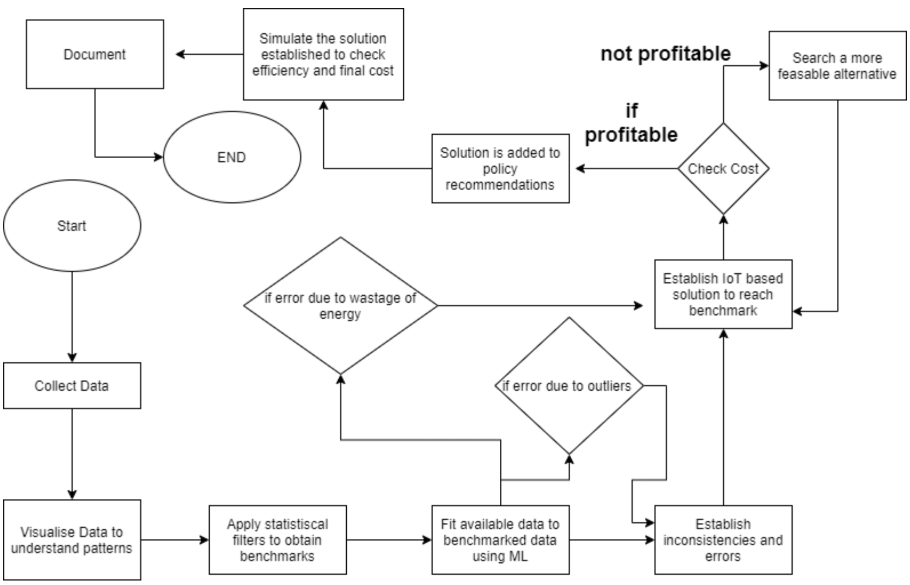
9. *"Multi-Layer Architecture and Routing for Internet of Everything (IoE) in Smart Cities"* by Sruthy Anand, et al., IEEE 2021.
Description: The authors propose a multi-dimensional architecture for Smart Cities and also emphasise on the need for users to engage with these devices in order to both generate data and help in emergency need of human assistance. The model proposed includes three layers – the cloud layer for deep learning and data analytics, the Middle-layer – which itself has several layers including Local data storage for faster computation, memory units and grid-computing; and finally, the edge layer that includes a huma-machine interface, the immediate services of use and local administrators. All the layers have human controllers in addition to their local microprocessors. At the end of their article, the authors have argued about the scalability of such a project and they have agreed that the project might actually work on the modern ide of distributed computing.

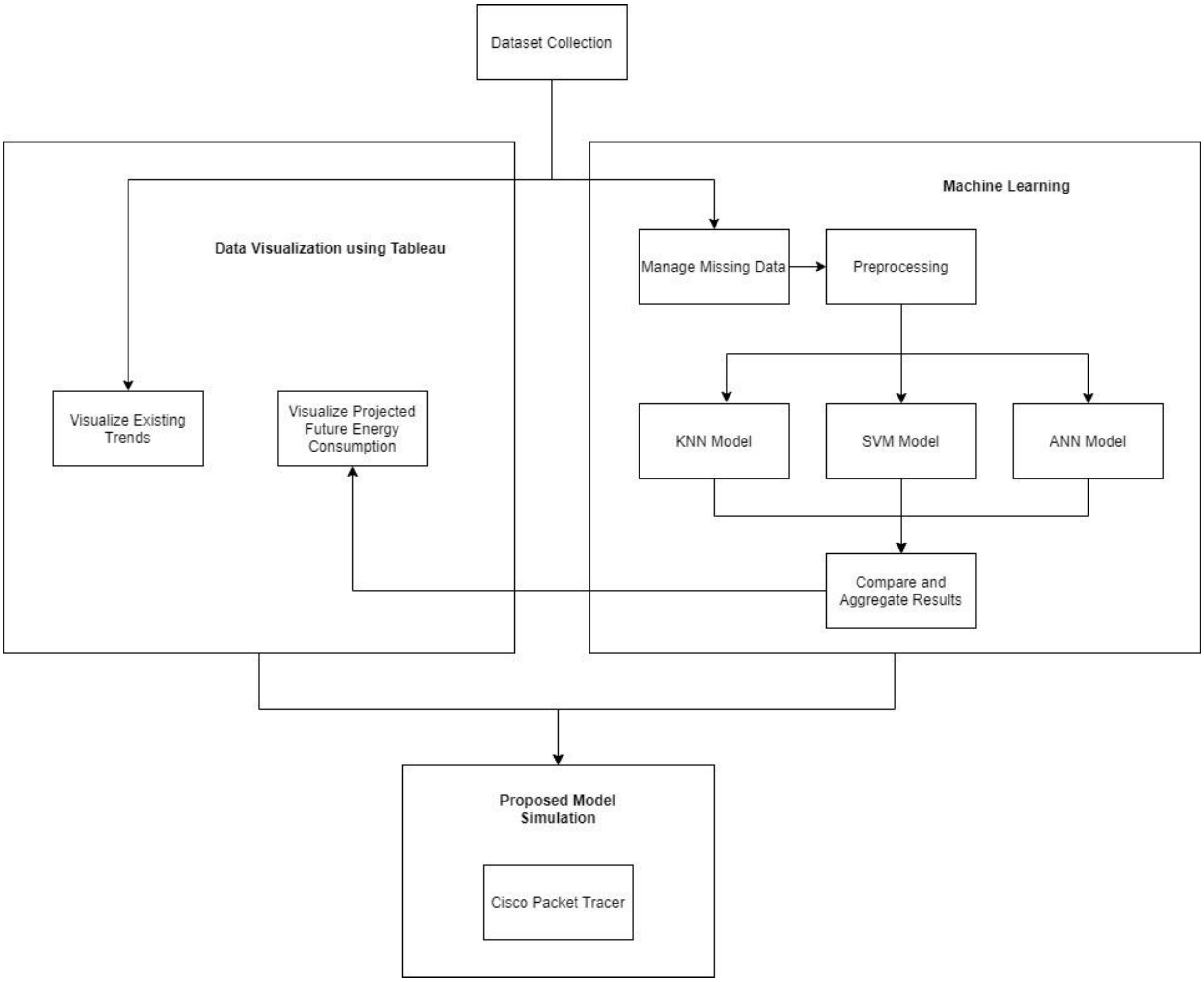
10. *"Optimizing Task Allocation for Edge Micro-Clusters in Smart Cities"* by Yousef Alhaizaey et al., IEEE, 2021.
Description: The authors have argued that the advent of 5-G Technologies and improved communication can be used to lay down a framework for a low-power and low-cost heterogeneous edge micro-cluster of devices and controllers to further the cause of smart cities. This would in turn minimize the memory requirements of the controllers (RAM and CPUs) and would create an automated mechanism for energy allocation and cluster-head election of the device nodes involved in the model. The authors argue that the allocation overhead was minimised and that real-life scenarios can be handled by algorithms like HE(mu)C due to their high scalability.

IV. Project Timeline



V. Project Flow





VI. Project Implementation

Proposed Solution: This project aims to study modern patterns of energy consumption and related costs and to further suggest IoT-based solutions for buildings and offices to improve upon the same. The highlights of this implementation are:

1. Data Visualization: The current energy consumption scenario is presented through graphs and other visual aids. This component covers research and analysis of the ratio of non-renewable to sustainable energy sources, impact of urbanization on energy consumption needs, impact of recent energy policies, projected energy wastage and several other factors.

2. Estimate Energy Savings in a Smart City: Utilizing the above data and a simulated scenario of a IoT-enabled office building, we predict the estimated energy savings provided by smart devices using machine learning algorithms.

3. Simulation of Proposed Model: The proposed model is presented as a simulation of an IoT-enabled office using Cisco's Packet Tracer tool, which gives insights on the exact amount of energy consumed by various devices with user-defined usage settings.

Data Collection

The following datasets were used:

1. IEA: natural gas consumption by region
2. IEA: Percentage Change in energy by source
3. US Gov: Primary Energy Renewable as a source
4. IEA: Share of Low Carbon Energy vs GDP PPP
5. World Coal consumption 1978-2020
6. Government of India Open-Source Data: Power Loss Across States between 2011-19
7. IEA: Petroleum and products demand: 1978-2020
8. IIT Bombay: Energy Usage in Individual Campus buildings Datasets 1-50
9. New York City Council: Hourly energy demand: 2001-2020
10. USA: Hourly Energy Demand over 20 years: PJME Incorporation
11. University of Boston: Hourly Energy Demand on Campus.

Visualisation

The visualisation was created using Tableau. The project is available at the given link:

https://public.tableau.com/app/profile/mohd.umar/viz/MohdUmar/CoverPage

Brief

The data that was collected was used to create several dashboards. Each dashboard is connected to the ones immediately concerned with them.

The dashboards have been created keeping in mind components like UX and UI – they are easy to understand and use.

Purpose

Data visualisation will make it easy for the concerned party to understand the critical requirement of the project being presented and the actual state of the world and environment as we know it instead of far-fetched numbers and tables.

Snapshots

Introduction Page

Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

Mohd Umar, 18BCE0196
Umang Mathur, 18BCE0746
Singh Aman Vinay Kumar,18BCE0725

World: sources of energy

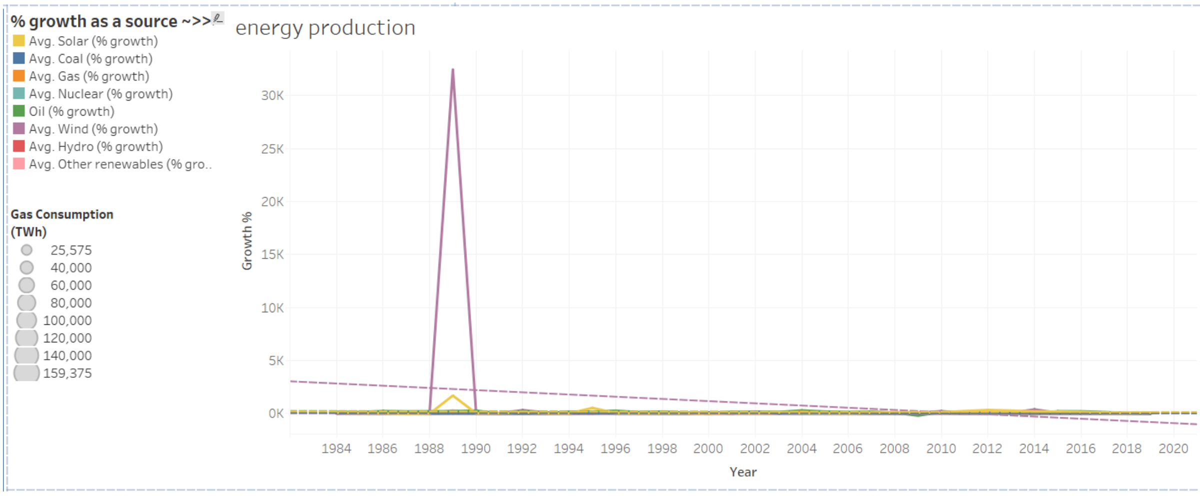
Money and Cleaner Energies

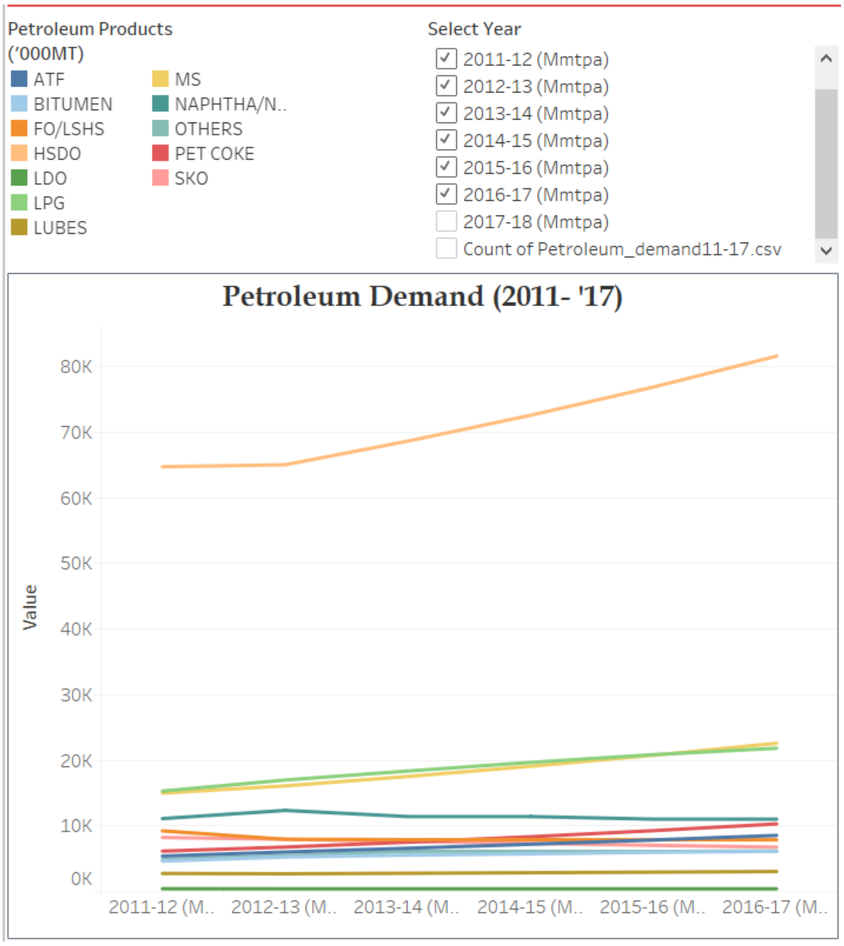
Urbanisation and energy access

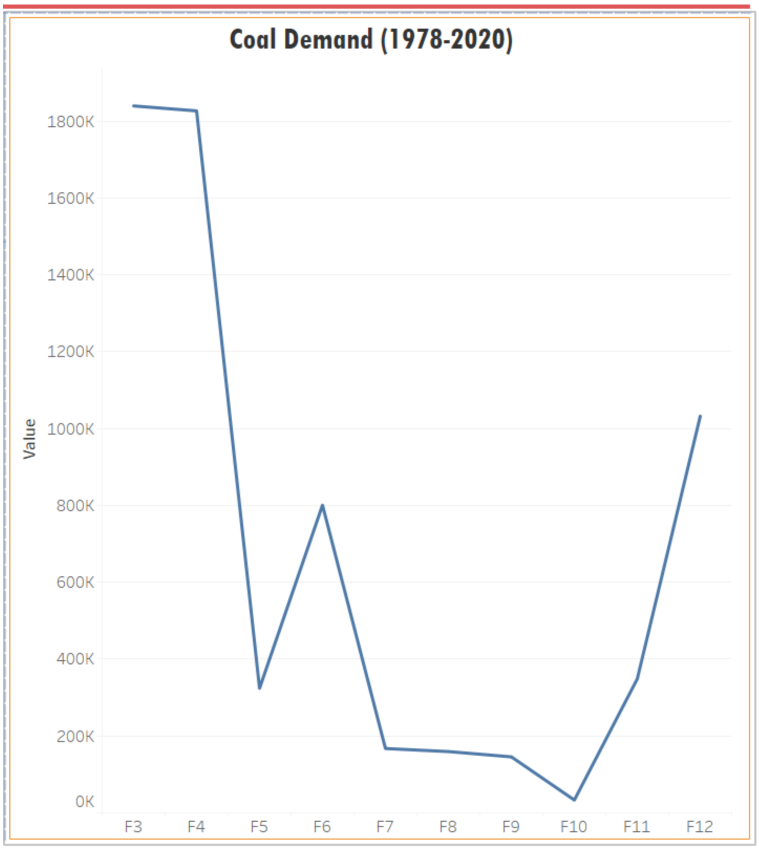
India and Electricity

case studies of 3 cities

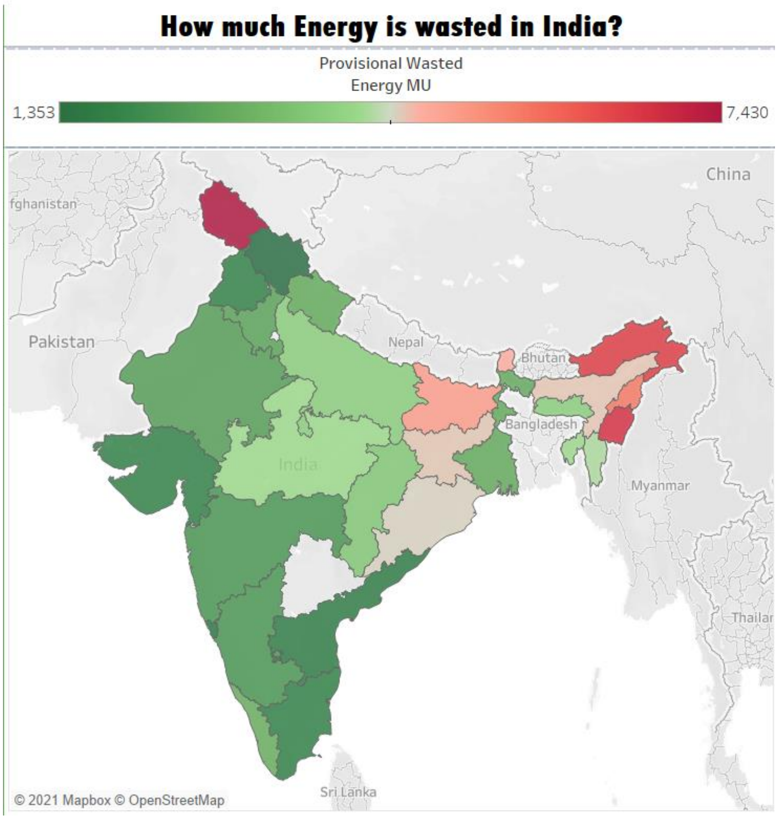
Energy Sources Trend

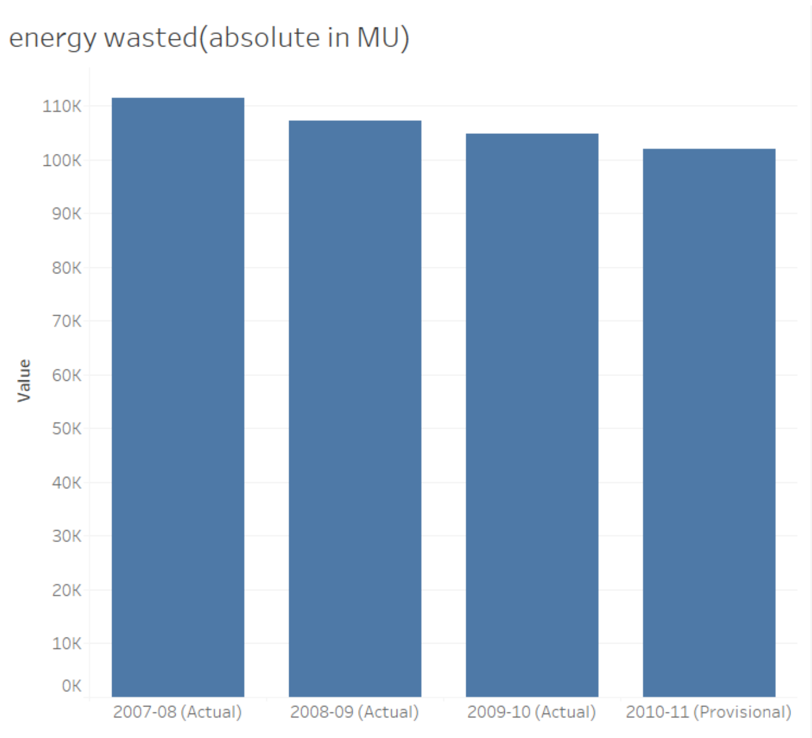



Petroleum Products ('000MT)
ATF
BITUMEN
FO/LSHS
HSDO
LDO
LPG
LUBES
MS
NAPHTHA/N..
OTHERS
PET COKE
SKO
Select Year
2011-12 (Mmtpa)
2012-13 (Mmtpa)
2013-14 (Mmtpa)
2014-15 (Mmtpa)
2015-16 (Mmtpa)
2016-17 (Mmtpa)
2017-18 (Mmtpa)
Count of Petroleum_demand11-17.csv
Petroleum Demand (2011- '17)
Value
80K
70K
60K
50K
40K
30K
20K
10K
0K
2011-12 (M..
2012-13 (M..
2013-14 (M..
2014-15 (M..
2015-16 (M..
2016-17 (M..


Coal Demand (1978-2020)
Value
1800K
1600K
1400K
1200K
1000K
800K
600K
400K
200K
0K
F3
F4
F5
F6
F7
F8
F9
F10
F11
F12

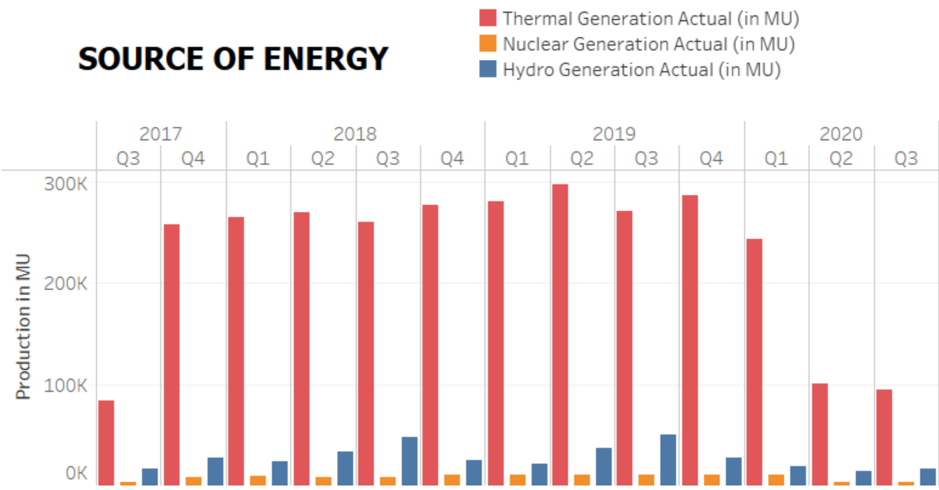
Energy Wastage and Sources in India

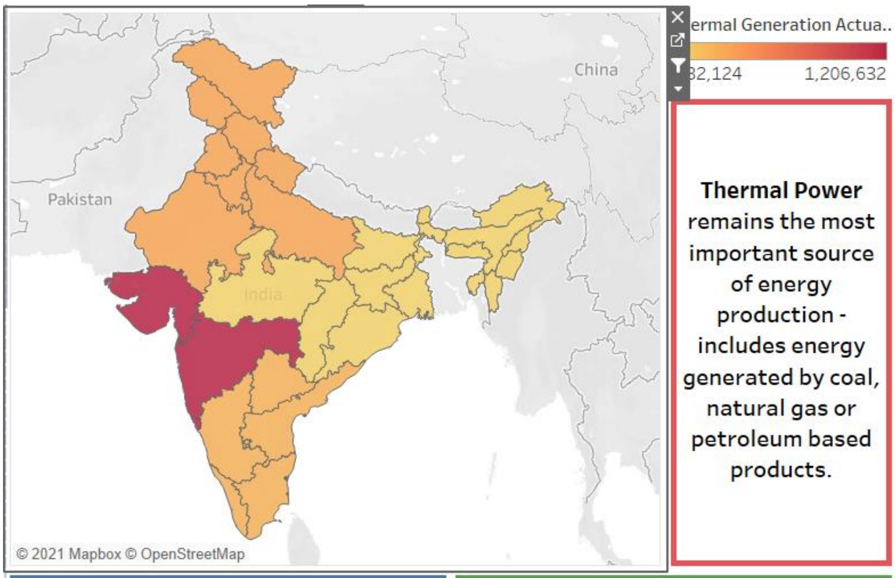




India is the world's 3rd largest producer and consumer of electricity.

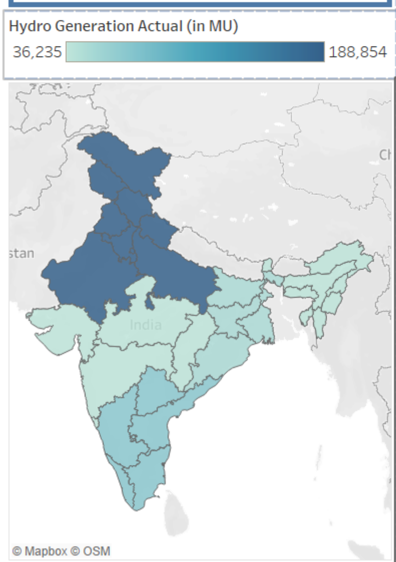
SOURCE OF ENERGY



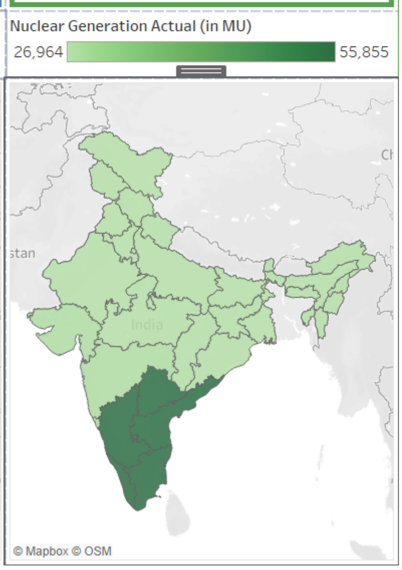


Thermal Power remains the most important source of energy production - includes energy generated by coal, natural gas or petroleum based products.

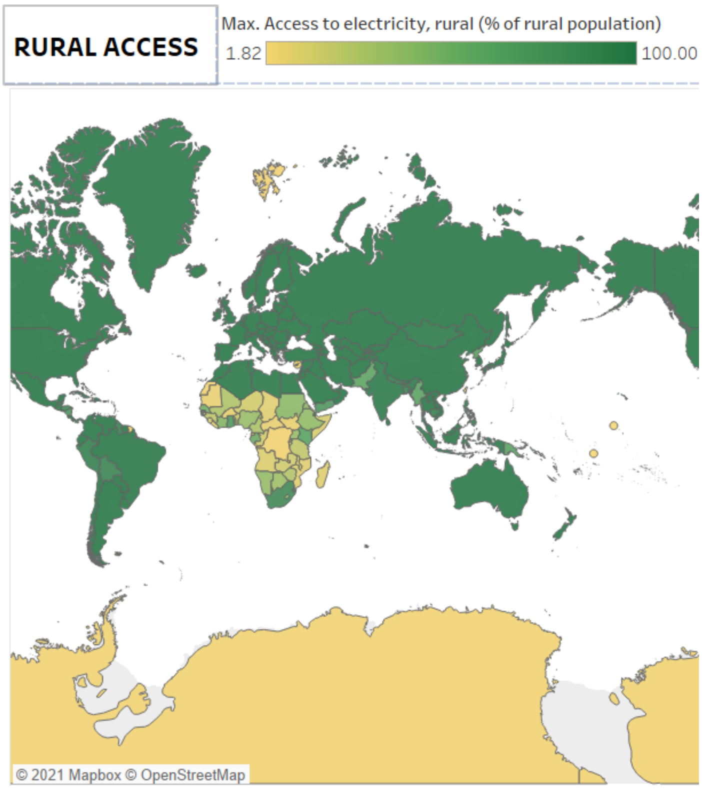
HYDROELECTRIC ENERGY

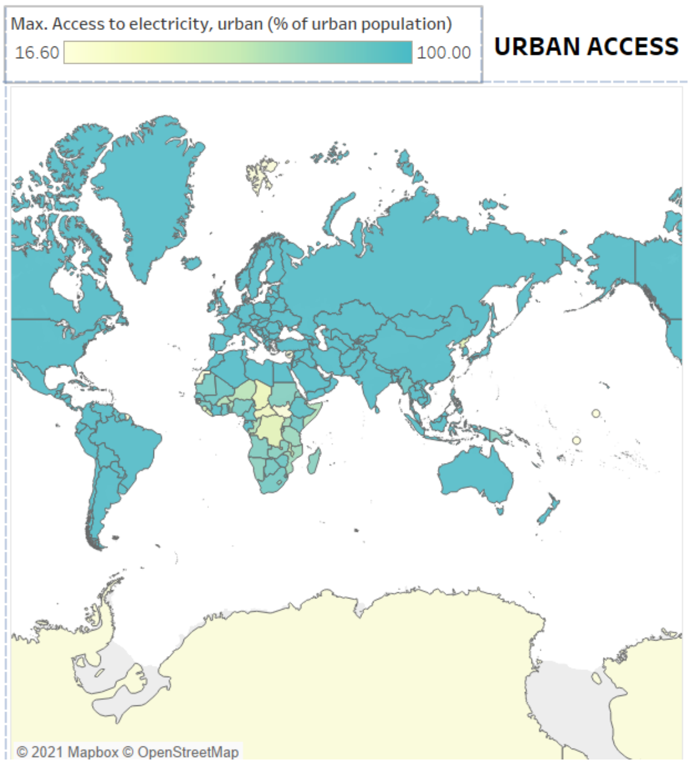


NUCLEAR ENERGY

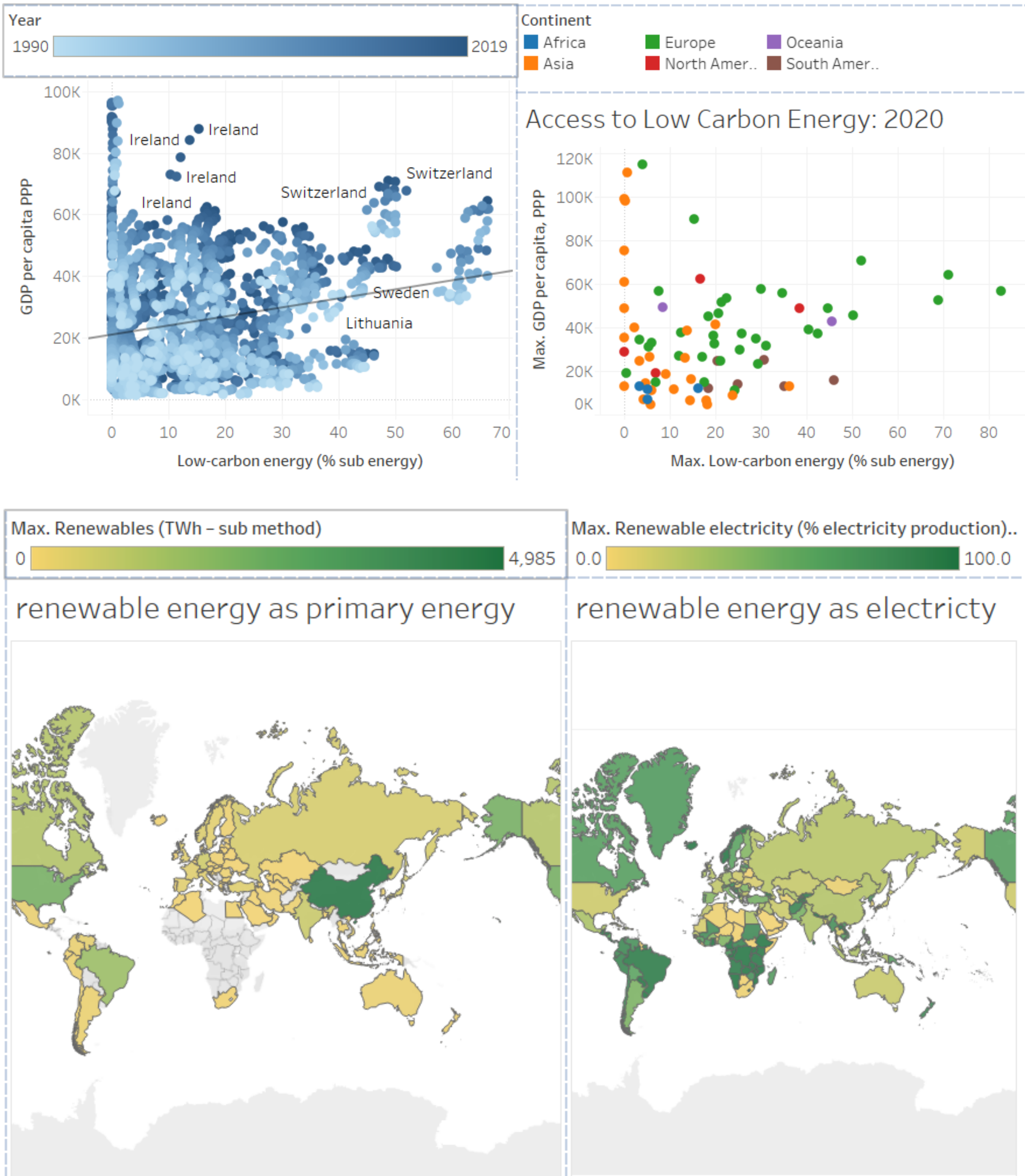


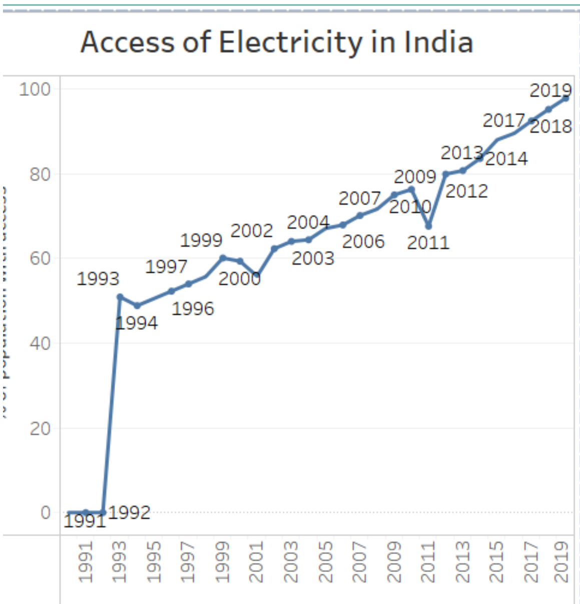
Global Access to Electricity





Global Access to Cleaner Energy Sources





Access of Electricity in India
100
80
60
40
20
0
1991
1992
1993
1994
1996
1997
1999
2000
2002
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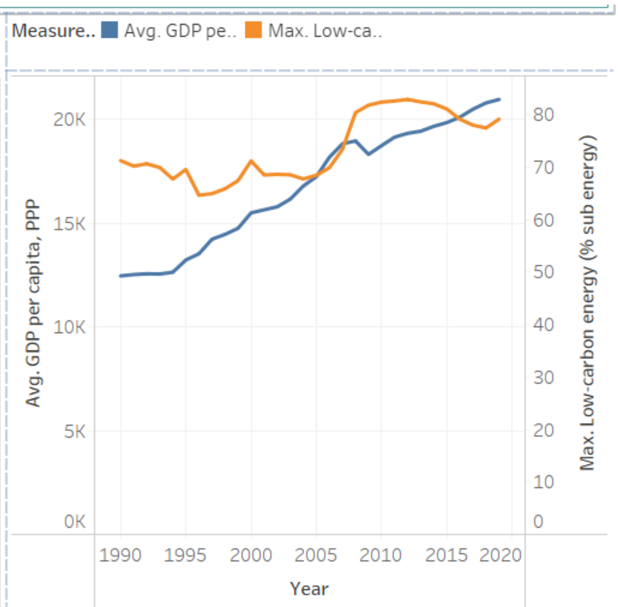
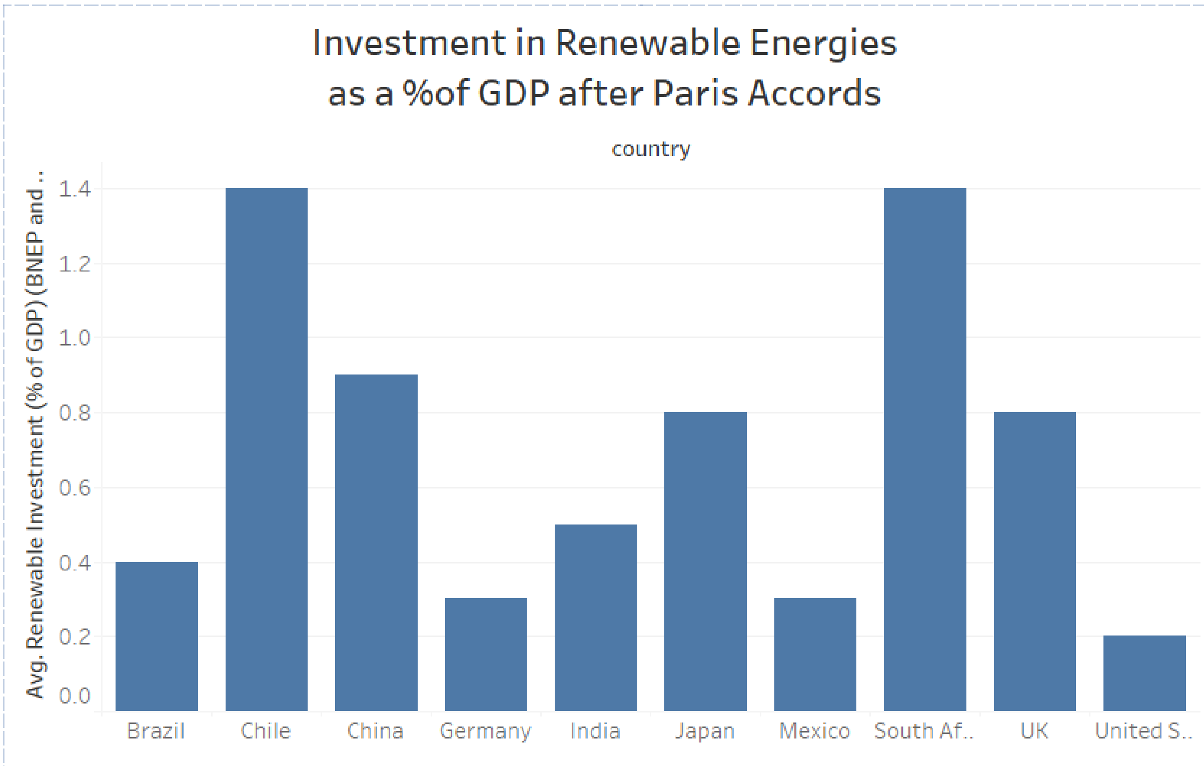
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019

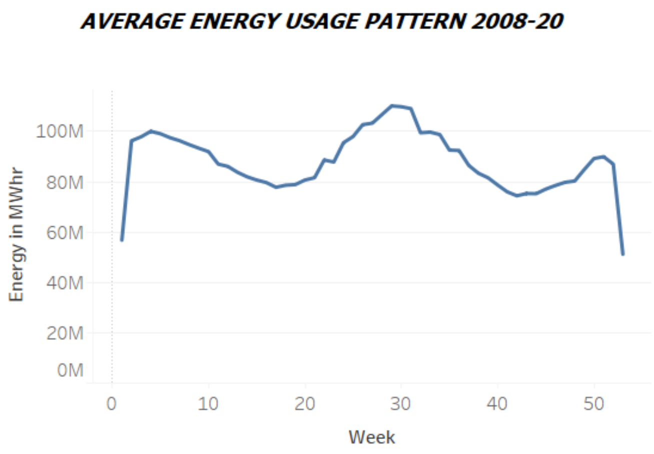


Measure..
Avg. GDP pe..
Max. Low-ca..
Avg. GDP per capita, PPP
20K
15K
10K
5K
0K
Max. Low-carbon energy (% sub energy)
80
70
60
50
40
30
20
10
0
1990 1995 2000 2005 2010 2015 2020
Year



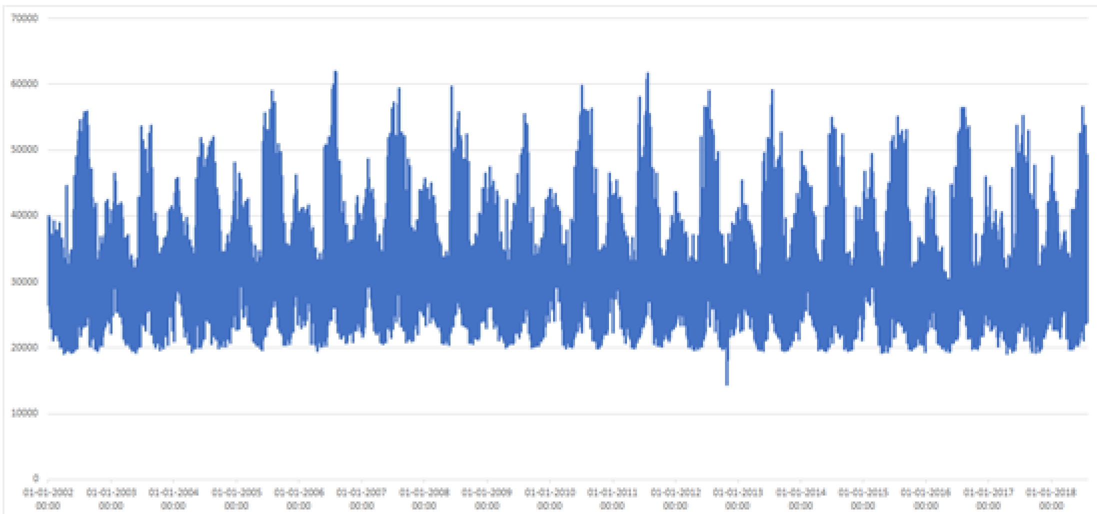
Investment in Renewable Energies
as a %of GDP after Paris Accords
country
Avg. Renewable Investment (% of GDP) (BNEP and ..
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Brazil
Chile
China
Germany
India
Japan
Mexico
South Af..
UK
United S..

Case Study of New York

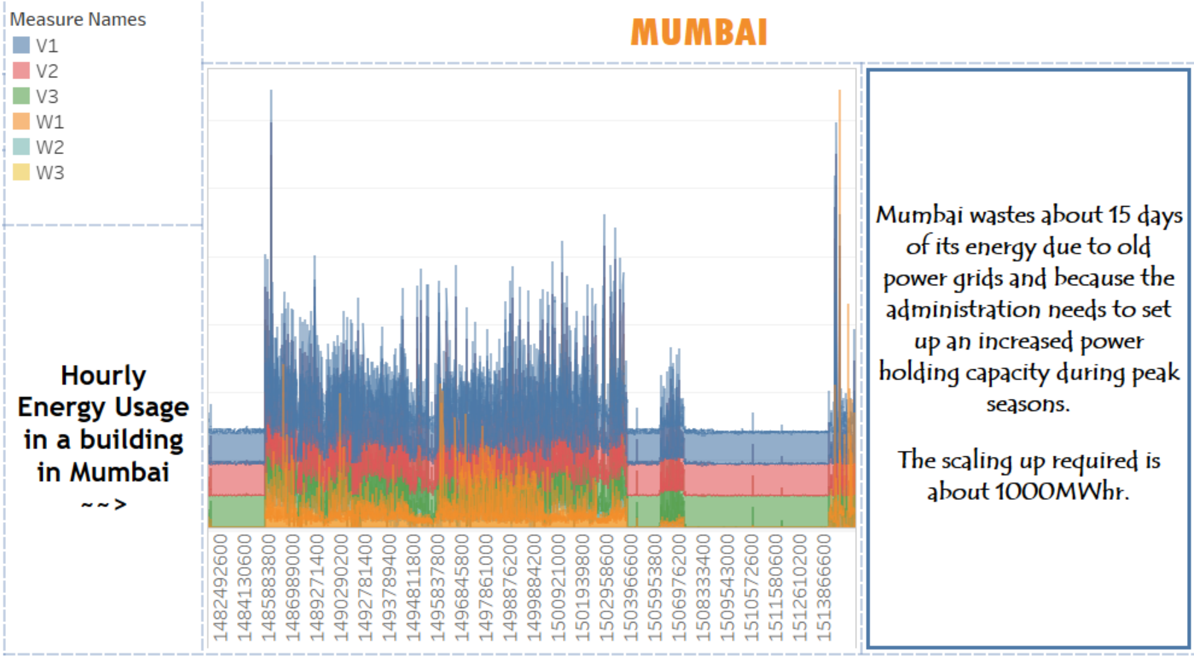


1. New York uses 22 times more energy than Kolkata.
(Most of it is used in heating and street lighting.)
2. 40% energy is used in Street Lights.
3. 18% energy is wasted in unused or semi-used public buildings.
4. USD 6 million - 20million is wasted in point 2,3 because non-sustainable technologies are used.

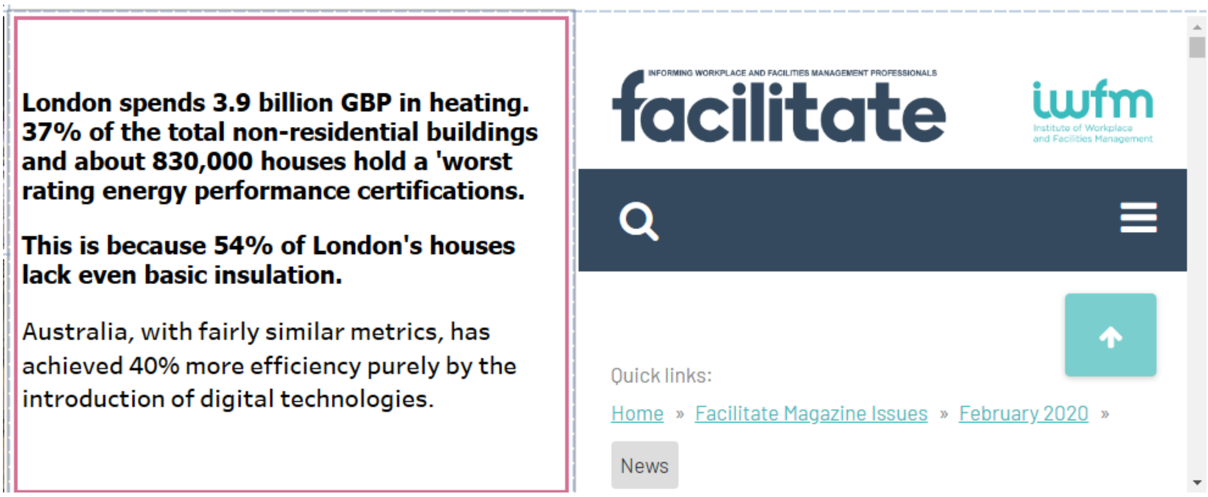
USD 6 million was wasted in 2019 by street lights alone.



Case Study of Mumbai



Case Study of London



Data Processing and benchmarking

Purpose

Data processing of the collected data was carried out to extract benchmarking features and attributes that can serve as a guideline for governments or local authorities to regulate power supply, be prepared to mitigate for shortages or identify key components of power loss.

Explanation

Very simple benchmarking procedures were carried out on the datasets. This included –

1. Curve-fitting
2. Estimation of statistical averages
3. Possibility of prediction

We establish that, statistical averages – most importantly the median serves as the strongest benchmarking tool for the data. In fact, medians varied only by about 5% on average and considerable changes occurred only when seasons changed in most cases. And since, median is a value that is very cheap to arrive upon, we set our benchmark as the seasonal median of the data. However, of course, in a real-world scenario, medians shall change according to national policies implemented by the state.

IoT implementation

After benchmarks have been set and energy usage patterns understood, the required IoT devices and communication services can be arrived upon to –

1. Minimise the costs involved
2. Maximise efficiency of energy usage
3. Make it comfortable for the owner to track the availability and usage of energy resources available to him/her/them.

The simulation shall explain it better.

Simulation using Packet Tracer

An office setup with all primary requirements of a building and the COVID protocols was devised on Cisco Packet Tracer.

Aim of the simulation:

1. To build a simulated model of a Hands-Free Smart Office where the need to touch is infinitesimal as possible in the vicinity and outskirts of the office.
2. To imply a budget friendly model accessible both to large- and small-scale organizations, outweighing the installation cost in the long run.

Components used:

Project Scenario	**Reason for Introduction**	**Sensors/Actuators Used**
Automated Door Lock	To introduce automation in door locking/unlocking and eliminate doors as a point of contact and hence probable hotspot of infection	RFID chip and scanners.
Automated Window	To introduce automation in window opening/closing and eliminate window as a probable hotspot of infection	***Sensors:*** Rain sensor, Photo sensor ***Actuators:*** The window lock, automated screw to close/open window
Solar Charged Battery	To introduce cost-efficiency in the project	Solar Cells
Theft Protection Mechanism	1. To reduce the possibility of a loss to the company. 2. To introduce cost efficiency by reducing the number of guards required. 3. Reducing number of guards reduces the possible chances of contact	***Sensor:*** Trip or motion sensor ***Actuator:*** Siren
Automated Coffee and Fan/AC	To eliminate the possibility of coffee machine or the fan/AC switch being a hotspot for infection	***Sensor:*** Trip or motion sensor ***Actuator:*** 1. Coffee dispenser 2. Fan/AC

Entertainment System	To introduce entertainment in the office while not adding to the possibility of an infection	***Sensor:*** The mobile receiver and transmitter connected via bluetooth to the music player ***Actuator:*** The music player + Speaker
Automated Street Lamp	To introduce vision near the organisation premises early in the day and then in the evening and night to facilitate better garage management	***Sensor:*** Photo sensor ***Actuator:*** The lamp bulb/LED
Automated Garage	To introduce automation in garage maintenance while reducing the possibility of human touch/contact.	***Sensor:*** RFID sensors and Motion sensor ***Actuator:*** Garage door
Fire Alarm + Sprinkler	To protect the economic and intelligent resources of the organisation	***Sensor:*** Infrared Heat detector ***Actuator:*** Siren + Water Sprinkler.

Sr. no.	Sensors/ Network devices used	Working Principle/ components	Application used in
1.	*WRT300N Router*	IEEE 802.11n protocol	Central hub for all IoT devices used in the scenario
2.	RFID	Scanner + Antenna	Used for maintaining attendance and garage admission.
3.	Rain Sensor	Resistive dipole based on moisture on the nickel poles on the sensor chip.	Used to find rains and high speed winds to open and shut the window automatically
4.	Photo Sensor	Resistive dipole based on the light energy received by the semiconductor used	Receives light has an output circuit used to provide electrical energy
5.	Solar Panels	photovoltaic effect	Uses the sensor and the solar cells to develop photo electricity
6.	Trip Sensor	Passive IR sensor in fire detection, Active IR sensor in Theft prevention modules	If the motion sensor is tripped the alarm rings and sends a message to the respective authorities.
7.	Smoke sensor	A radioactive material, usually depleted Uranium or Radium is sandwiched between semiconductors. The radioactive element reacts with smoke and conductivity suddenly increases that rings the alarm.	Detecte the CO2 in the environment and call in the required function .

Additional Components needed:

Two custom-programmable MCUs or microprocessors. They have been used to:

1. Ensure that the fire water sprinkler water reservoir is maintained.

2. Ensure that the rain sensor converts its series resistance to parallel as soon as water touches it, increasing conductivity manifolds and facilitating the closing of windows. Similarly, as soon as the water contact is broken off, the sensors reopen the window and set resistance to series.

A laptop / mobile / computer to manage the IoT structure through a MQTT facilitated cloud.

Protocols Used:

1. **Bluetooth**: Bluetooth has been used as the primary protocol for connectivity in the kitchen to play music.

2. **WiFi 4.0:** WiFi4.0, which has been referred to as its parent protocol IEEE802.11n has been used as the protocol to connect all IoT devices to the WRT300N router. This is done to reduce the possibility of dead ends.

3. **MQTT:** MQTT has been used as the primary protocol to connect the office server to a larger organisational cluster. This is done to facilitate network stability even during limited bandwidth and constrained weather conditions.

All the protocols have been discussed and enumerated in appendix A.

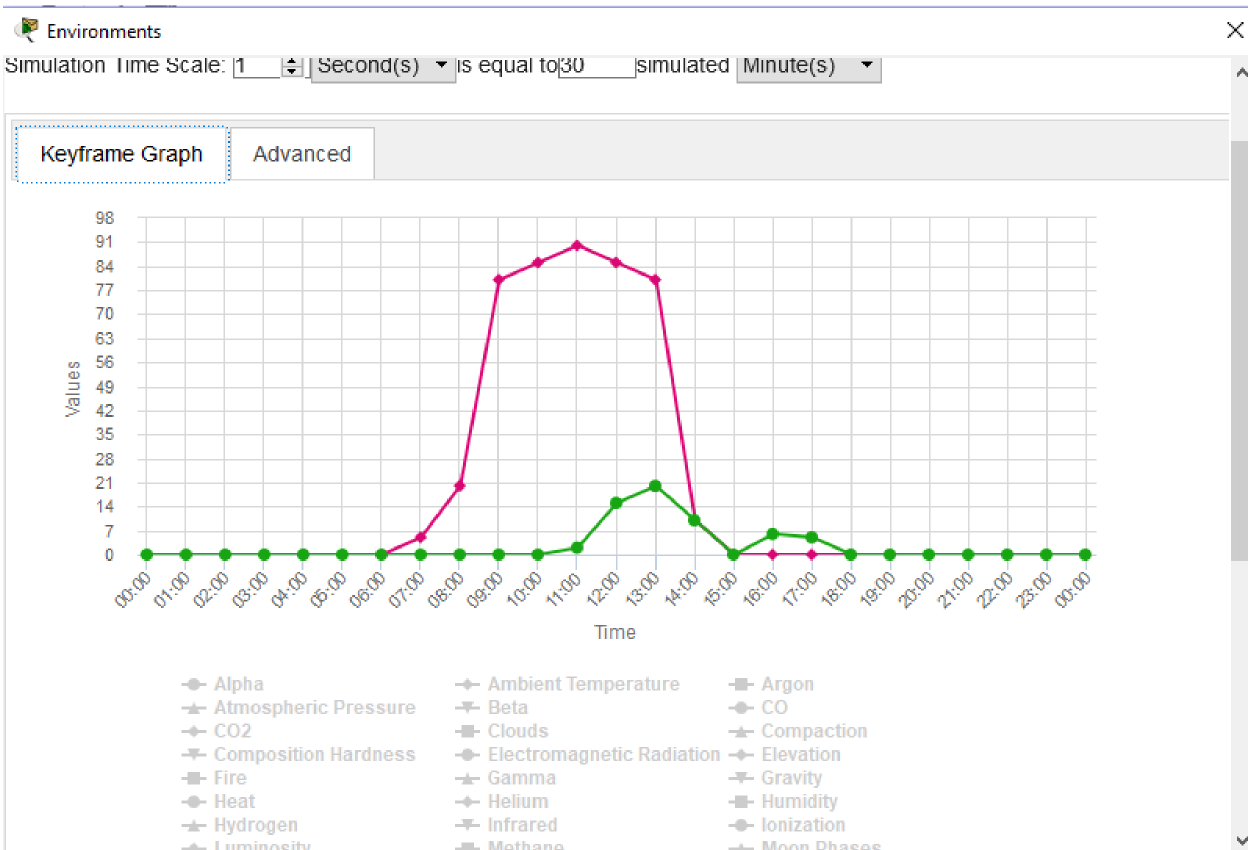
Proposed Architecture:

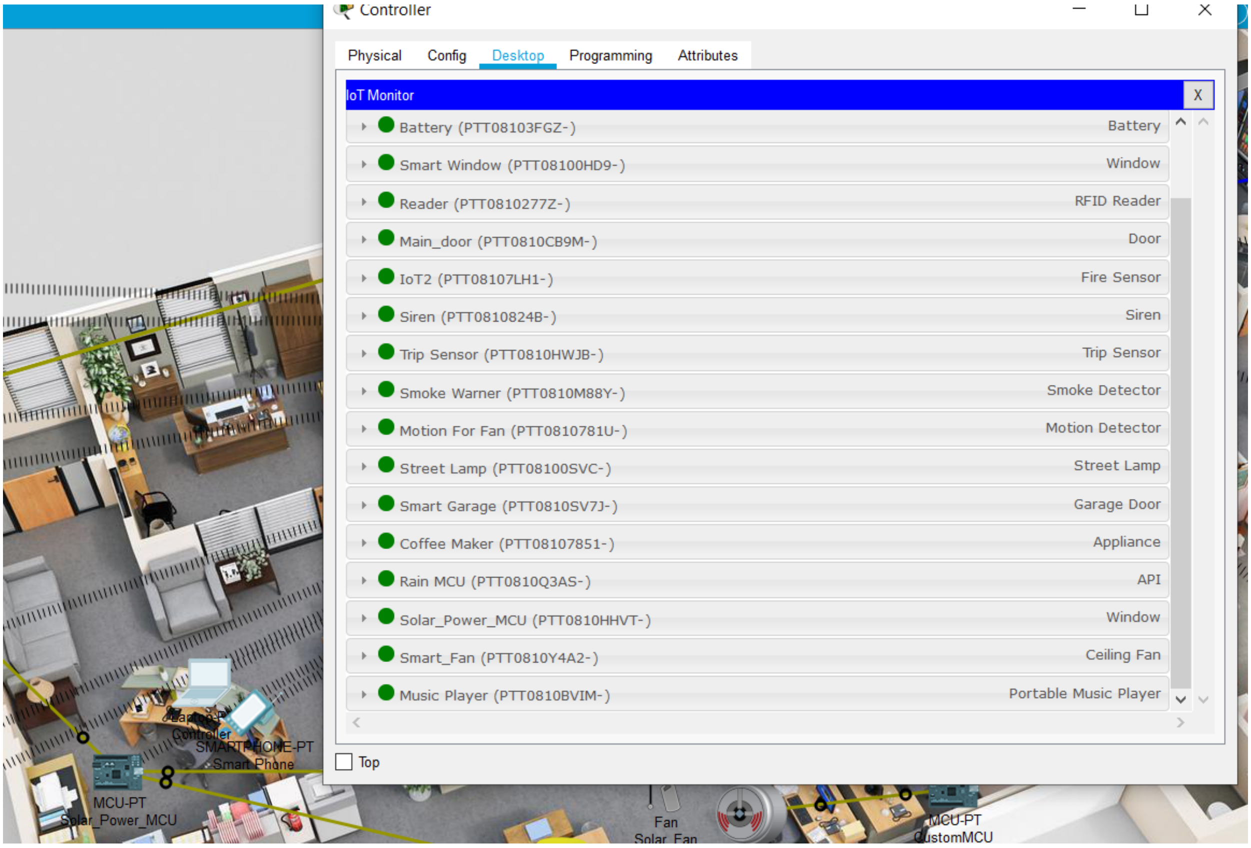
The Project does not obey any specific algorithm. It is a use-case suggestion model. So, we have set up a basic office as depicted in the image in this section. The office is subject to real-world variables like rainfall, wind, sunshine etc., the option to which was available in the simulation software.

1. The office has a WRT300N router that is connected to all other IoT devices.
2. The WRT300N router is itself connected to a modem that is connected to a larger cluster or server.
3. A laptop or a mobile is sufficient to keep track of all IoT devices used. This fact is also demonstrated.

The office setup is shown here:

The sensors maintain a record of about 20 environment variables.

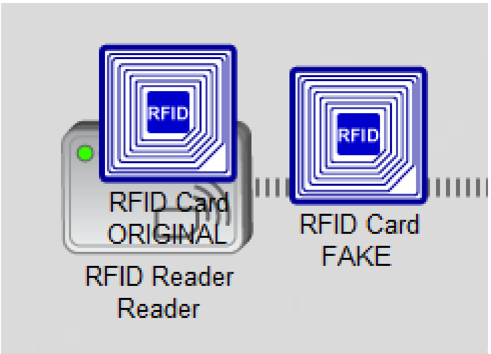




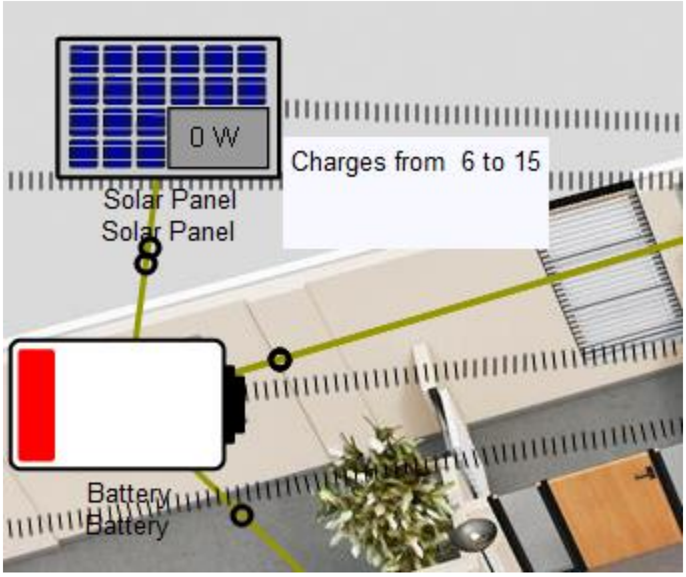
All the environment variables and the IoT devices can be accessed at a common laptop/mobile/computer available with the office manager.

Snapshots:

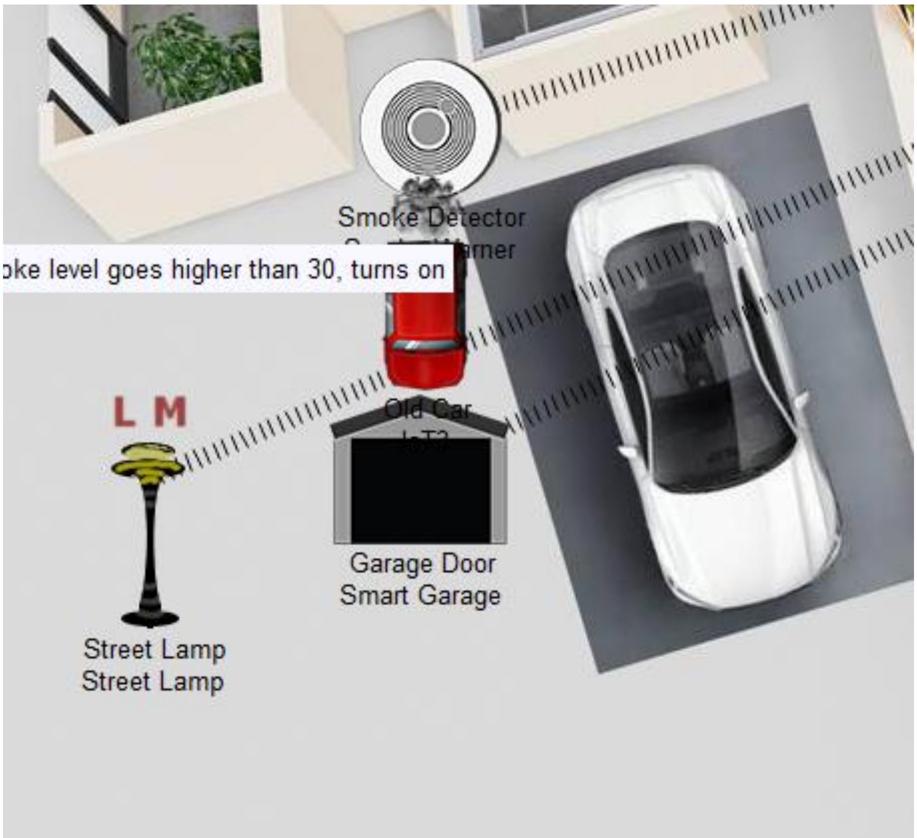
Here are some snips from our project.



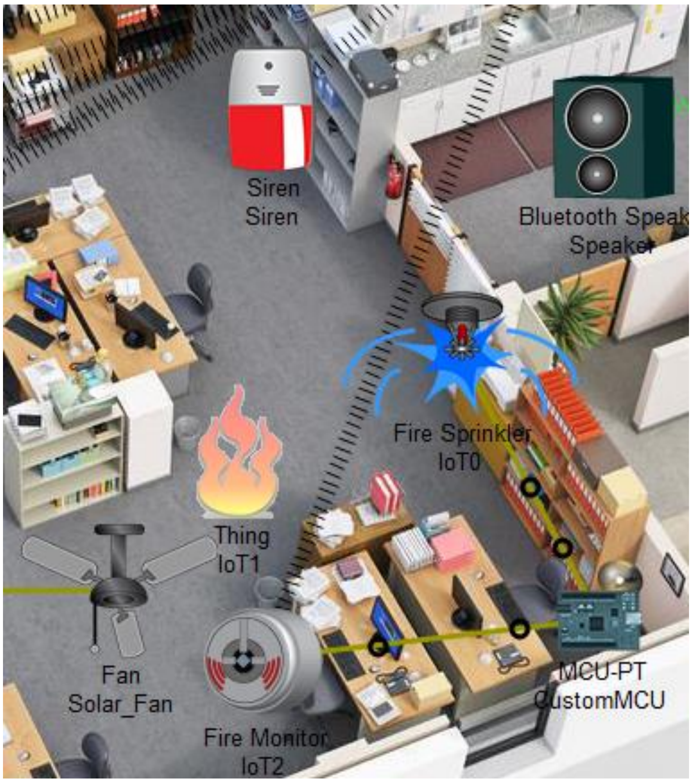
RFID CARD and READER in action



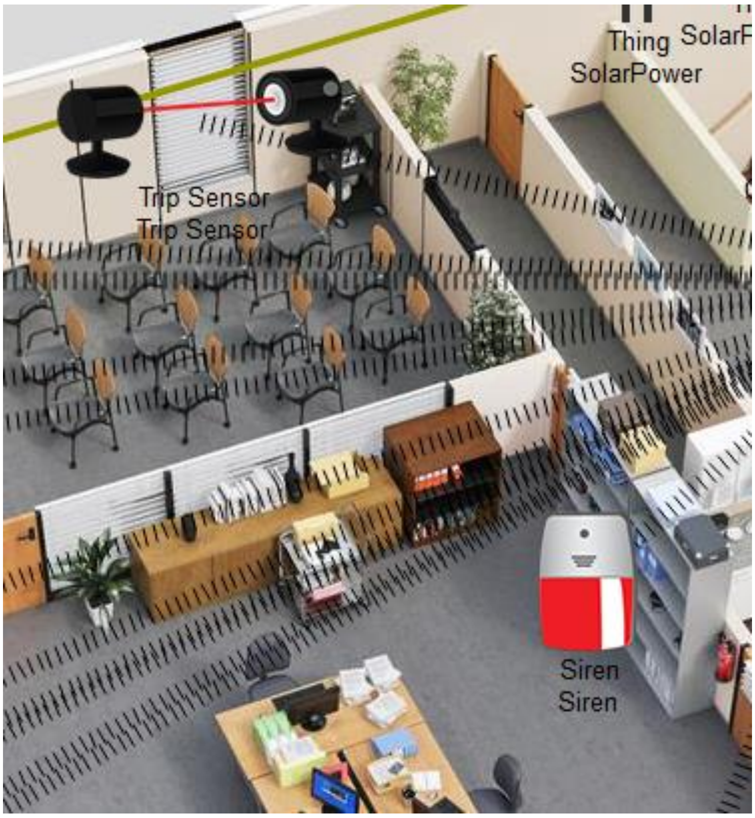
The solar powered battery in charge



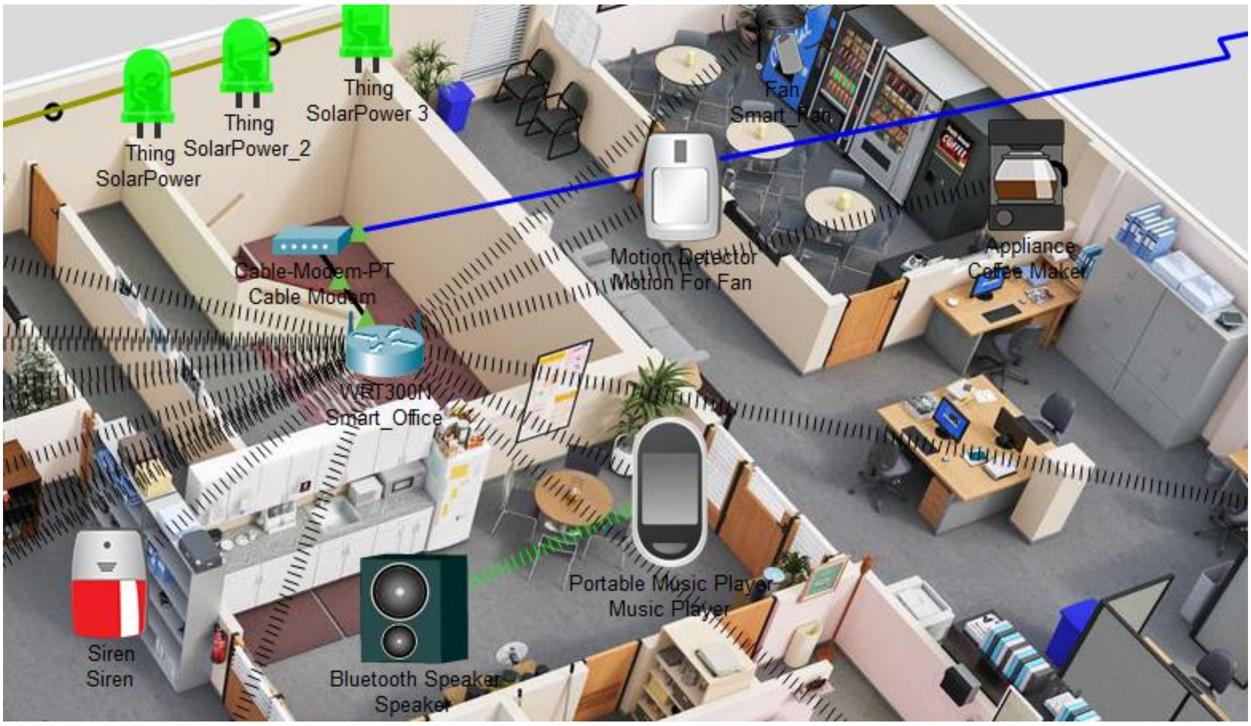
Smart Garage in action. The door is open and the car emits smoke. (CISCO packet tracer clearly offers a great number of tools)



Motion sensor and fire alarm in action

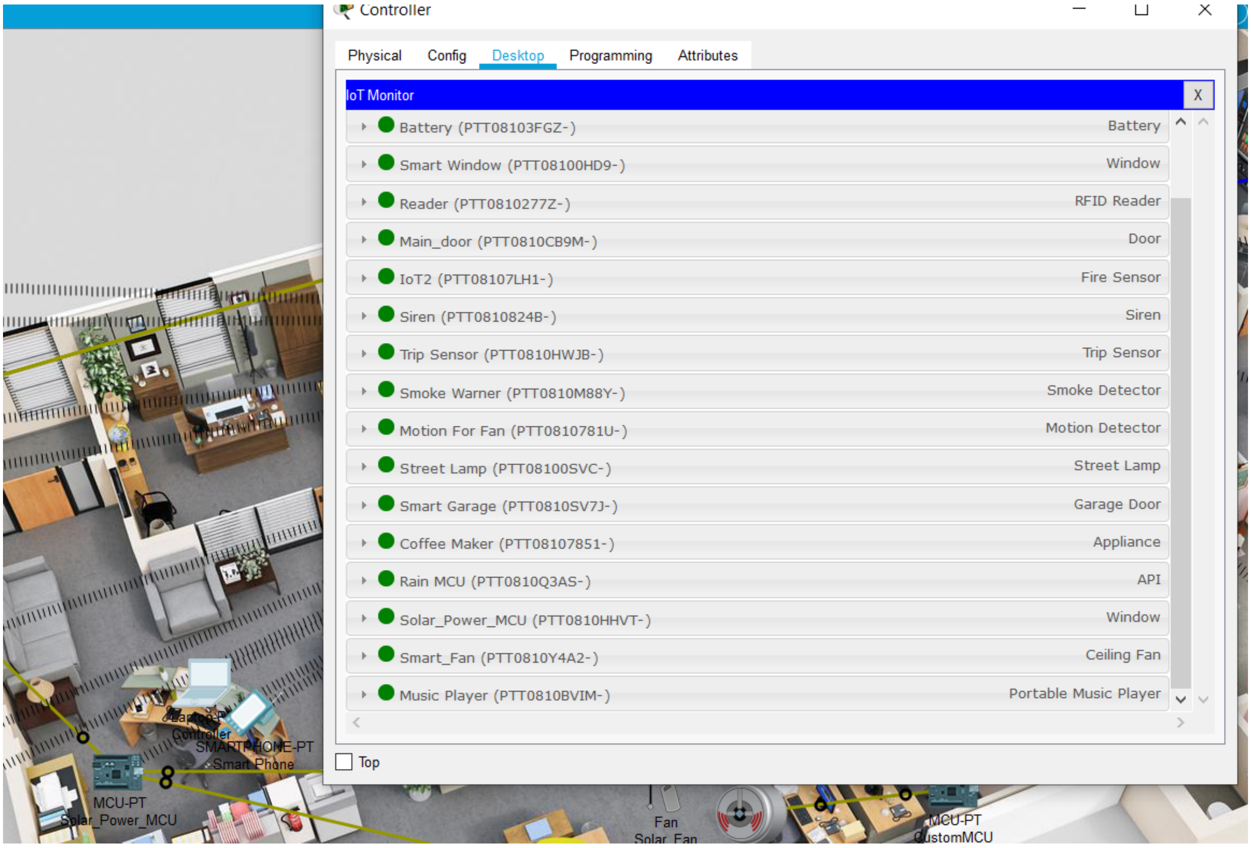


The trip sensor i.e. the theft detection module in action



The music speaker

The smart Window module



A laptop or a mobile can be used to detect the state and signal of IoT devices.

Component and maintenance Cost:

The following should summarise the cost of building and maintaining of the model -

Components Used	**Purchase cost / Subsidy (if any)**	**Maintenance Cost (yearly)**
RFID	About 10,000 INR. This has to be spent only once.	Battery lasts for an average of 4 years. And a general mechanic So, on an average, the maintenance cost is around 200 rupees per year.
Rain Sensor	150 INR*4	2 years lifetime with minimum maintenance requirement.
Photo sensor	1000 INR * 2	2 years lifetime with minimum maintenance requirement.
Solar Panels	2 lakhs INR (with 60% subsidy)	No maintenance needed for about 20-25 years.
Solar battery	18000 INR (base) * 4 (number)	No maintenance needed for 5-7 years.
Active IR sensors	400 INR - 500 INR	2-3 years lifetime with minimum maintenance
Passive IR sensors	100 INR - 200 INR * 3	3 years lifetime with little or no maintenance
Fire Alarm Sensors	700 INR*5	Maintenance every 6 months. The cost involved is the charge of the mechanic.
Fire Water Sprinkler	1000 INR * 3	Maintenance every 6 months. The cost involved is the charge of the mechanic
Programmable MCU	300 INR	No maintenance needed for about 2-4 years
Bluetooth Speaker	1200 INR	No maintenance needed for about 12-18 months.
Routers	8000 INR	Maintenance once a year

Extra Installation Cost:

These costs have to be borne only once.

Office Space Module	**Installation Costs involved**
Kitchen (requires Bluetooth speakers + music system)	0
Garage	About 14,000 INR
Coffee Vending + Fan	About 5000 INR
Street Lamp	About 8000 INR to construct the lamp
Theft Protection	About 2000 INR
Battery	About 2000 INR
Door Lock	About 10,000 INR for all the doors
Fire Alarm	About 5000 INR

Total cost of components and basic establishment is around 2,30,000 INR/office. These costs do not repeat themselves.

Finally, installing a cloud may cost around 4.5 lakhs INR per year, which can be scaled down to about 2.8 lakh per year using a premise-based server.

However, since we are using a MQTT server, a limited server with even reduced costs may be used for the connections.

So, the total cost of installation of the components including their base cost adds up to about 2.3 lakhs with an optional expenditure of about 3 lakhs per year depending upon the scaling of cloud the organisation needs.

Comparison against real-time costs:

As per research, the loss in productivity in Indian scenario is about 57% which is very high compared to only about 33% in the UK. Most of this is due to stress, anxiety and isolation. This also means that the costs involved in wellbeing increase both on the balance sheet of the company as well as the employee.

So, it is pretty apparent that a smart office is an urgent necessity.

1. The solar panel saves about 18 lakhs INR in electricity costs every year, given the scenario of India being a country rich in sunlight. In Arizona, USA - the savings are less, around 10000 USD per year (around 8,00,000 INR).
2. Elimination of any office staff responsible for relaying and carrying messages and files by digitizing everything saves around 8.5 lakh INR per year (given the basic bay of office clerks being around 2,40,000 INR per year in India). The savings increase in case of countries like the USA and the EU where minimum wages are higher.
3. Fire damages can cost a company about 30-90% of all its hardware and intellectual resources. This could also mean that a company could face heavy losses in future to re-establish systems. A fire alarm would be a very small investment given the possible losses. Business Sprinkler Alliance computes fire related losses to cost around 230 million pounds per year (about 2000 crore INR) in the UK alone.

All this means that using the proposed model is way more cost efficient than a regular office set up with all the installation costs covered up in about 2-3 years. After that, the organisation shall actually make profit with the organisational set-up and the smart office model proposed.

VII. Results

We successfully predict that –

1. Energy resources have gone massive over-use and wastage
2. Energy resources from renewable sources are easy to avail and cost effective to utilise.

And simulated a model to prove in theory that –

1. IoT can be used to tackle the global problems of energy over-expenditure, energy wastage and a lack of energy policy globally.
2. Urban spaces can profitably conserve energy resources while using technologies associated with IoT.

And thus establish a methodology to study and plan urban energy grids and distribution network while also giving the policy makers a fundamental upon which energy policies can be built, which was the primary aim of the project.

VIII. Conclusion

We hereby conclude our project with all the results established in the previous section with the note that our project was based on simulating real world data, while in more practical terms, real-life data faces variations on more granular levels. This is beyond the scope of our computational capacity as well as the fact that data at such granularity is not available for students or researchers.

Appendix A: Protocols

The protocols used in the project are -

MQTT

Originally developed in 1999 to monitor oil and gas pipelines over remote satellite connections.

We have used the MQTT protocol because -

1. Message Queuing Telemetry Transport
2. Lightweight
3. Publish-subscribe messaging transport model
4. designed for the constrained devices and with low bandwidth,
5. easy for communication between multiple devices

IEEE 802.11N

Standard protocol for WiFi 4.0

Uses multiple antennas and multiple nodes to reduce the probability of any dead point. This makes it a cost effective protocol as compared to protocols that rely on stronger signals. So, IEEE802.11n fits perfectly with MQTT.

Bluetooth

Bluetooth is a wireless networking protocol that uses radio waves in the bandwidth 2.402 to 2.48 GHz. Typically has a maximum range of 10m.

Appendix B: References

For IoT simulation

1. T F Prasetyo et al 2018, "J. Phys.: Conf. Ser. 1013 012189 Prototype of smart office system using based security system"

2. Dony Susandi et al 2017, "Smart Parking System Pada Prototype Smart Office Berbasis Internet Of Things"

3. Ping Shum et al 2018, "Smart Office: A Voice-controlled Workplace for Everyone"

4. Arnau Erola et al 2015, "Smart Insiders: Exploring the Threat from insiders using the Internet-of-Things"

5. Jianli Pan et al 2015, "An Internet of Things Framework for Smart Energy in Buildings: Designs, Prototype, and Experiments"

For the Project Literature

1. "The 2018 International Energy Efficiency Scorecard", Fernando Castro-Alvarez, Shruti Vaidyanathan, Hannah Bastian, and Jen King, ACEEE, 2018

2. "Improving Building Energy Efficiency in India: State-level Analysis of Building Energy Efficiency Policies", Sha Yu *et al*, Energy Policy, Volume 110, 2017

3. "IoT for the Failure of Climate-Change Mitigation and Adaptation and IIoT as a Future Solution", Nesma Abd El-Mawla, Mahmoud Badawy, Hesham Arafat, World Journal of Environmental Engineering, 2019

4. "A review on Internet of Things solutions for intelligent energy control in buildings for smart city applications", Iman Khajenasiria, Abouzar Estebsarib, Marian Verhelsta, Georges Gielena, Energy Procedia 111, 2017

5. "Internet-of-Things-Based Optimal Smart City Energy Management Considering Shiftable Loads and Energy Storage", Hêriş Golpîra, Salah Bahramara, Journal of Cleaner Production, 2020

6. "The Network Architecture Designed for an Adaptable IoT-based Smart Office Solution", Karol FURDIK, Gabriel LUKAC, Tomas SABOL, Peter KOSTEL, International Journal of Computer Networks and Communications Security, 2013

7. "A Systematic Survey on the use of Fuzzy Graph Structures in India'sSmart City Development" by B. Angel, and D.Angel, IEEE, 2021.

8. "IoT Smart City Architectures: an Analytical Evaluation", by Mahdi Fahmideh et al., IEEE, 2018.

9. "Multi-Layer Architecture and Routing for Internet of Everything (IoE) in Smart Cities" by Sruthy Anand, et al., IEEE 2021.

10. “Optimizing Task Allocation for Edge Micro-Clusters in Smart Cities” by Yousef Alhaizaey et al., IEEE, 2021.

Appendix C: Links to visualisation and simulation for reference

Link to Visualisation Dashboard:

https://public.tableau.com/app/profile/mohd.umar/viz/MohdUmar/CoverPage

Link for the files necessary for Cisco Packet Tracer simulation

https://drive.google.com/drive/folders/1vchwK5FmWVEs3Z_ACF1vSg_-_8YUm8Ua?usp=sharing