Green Planning Systems for Self-Consumption of Renewable Energy

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Abstract—Rising temperatures on Earth have led to the exploration of new technologies to help curbing the severe effects of Climate Change. Green Planning systems belong to a new type of Internet-based technology that aim to use computing resources efficiently to reduce energy consumption and CO_2 emissions. The rapid advancement of renewable energy generation infrastructure and the lack of energy storage solutions at scale have highlighted the importance of energy self-consumption principles in new domains (e.g., heating/cooling, electromobility, appliances), which refer to the process of intelligently consuming energy at the time it is available. This paper analyzes existing green planning systems, energy management applications, and future challenges deploying self-consumption of renewable energy. We also present experiences of a green planning system we developed in-house. Our overview and categorization will be helpful to a variety of researchers, practitioners, and policy makers to make their systems environmentally friendly.

1 Introduction

Global Warming refers to an increase in global surface temperatures caused by humans that has progressively led to Climate Change, which is defined as new weather patterns that persist for an extended period of time and have an influence on the environment and human health. CO_2 levels have been steadily rising since the Industrial Revolution (1760 – 1840 AD), according to the Intergovernmental Panel on Climate Change[1]. A key driver for the production of CO_2 is the current human activity, as 85% of CO_2 emissions come from the burning of fossil fuels with data from the US Environmental Protection Agency[2]. Carbon dioxide traps solar radiation within the atmosphere, resulting eventually to Global Warming: oceans clean only ¼ of CO_2 pollution, while trees another ¼. The global greenhouse gas emissions originating from electricity and heat production (25%), transportation (14%) and buildings (6%), already make up almost half of the planets gas emissions besides: agriculture (24%), industry (21%) and other energy requirements (10%).

Green Planning refers to computational approaches that aim to improve environmental quality and make rapid progress towards sustainability. It is characterized by a longer-term perspective, as it is designed to replace more conventional methods for protecting the environment and natural ecological values, by taking into consideration economic realities. Green planning systems propose sustainable alternative techniques to various modern activities and applications that are causing damages to the biosphere [1]. It is an attempt to integrate the scientific interests of society to develop intelligent strategies that can achieve sustainable prosperity for the current and future generations, while supporting the natural ecosystems. A key driver for controlling the CO_2 emissions is the uptake of *Internet of Things (IoT)*, which connect computing equipment in a way it is able to "think", "see", "react", "hear", perform various operations, as well as communicate using open protocols. Thus, energy usage and CO_2 emissions governed by IoT infrastructure can be brought together under the same roof. According to Gartner[3], an average household in the developed world owns approximately 5-10 internet-connected gadgets, such as smart TVs, smartphones, smart-home devices, etc., and it is predicted that this number will escalate to 100 billion connected smart devices by 2030 [2].

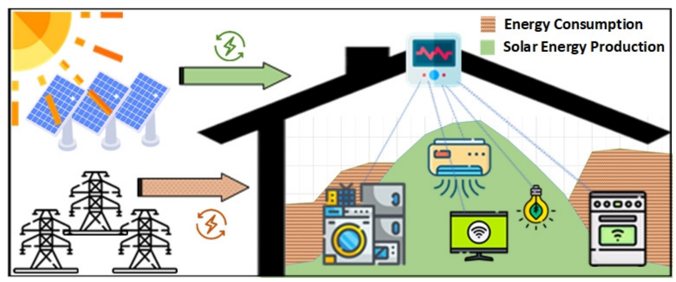

Fig. 1. An example of a sustainable and cost-effective green planning of appliances during the day that optimizes self-consumption of renewable energy.

Self-consumption is the act of using local renewable energy to operate devices (e.g., white appliances, HVAC, EV charging, IoT-enabled gadgets) during energy production. Thus, it can promote the integration of variable renewables into the grid and reduce the total costs of the energy system through load shifting. Demand Response (DR) is an adjustment in the energy consumption of an electric utility customer to better match the power demand with the supply, by shifting or reducing their electricity usage during peak periods in response to time-based pricing rates [14]. However, without further technical enhancements in DR the self-consumption potential is limited. These types of solutions can accommodate

1. IPCC, URL: https://www.ipcc.ch/sr15/
2. US Environmental Protection Agency, URL: https://tinyurl.com/zkp5s5ru
3. Gartner Inc., URL: https://tinyurl.com/5ykd62pc

TABLE 1
Green Planning Systems and Energy Management Applications

Systems/Applications	Algorithm/Technology	User Comfort	Energy Storage	Renewable Energy	User Preferences	Perspective
Gemello [3]	k-nearest neighbors algorithm	Not considered	×	×	×	Long-term
Arup Smart Workplace	Arup AI-powered tools	Considered	×	×	✓	Short-term
Deep Latent Generative Model [4]	Variational recurrent neural net.	Not considered	×	×	×	Long-term
GreenerBuildings	Viterbi Algorithm	Considered	×	×	×	Short-term
IoT-Based A/C System [5]	Extreme Learning Machine	Not considered	×	×	✓	Short-term
ILPSS (HVAC) System [6]	Integer Linear Programming	Considered	×	×	✓	Short-term
Google Nest Thermostat	Google AI Learning Thermostat	Considered	×	×	✓	Short-term
Ecobee 3	Ecobee 3 AI Thermostat-IFTTT	Considered	×	×	✓	Short-term
Sunny Home Manager	SMA Solar AI Technology	Considered	✓	✓	✓	Short-term
Edge-based HEMS [7]	Dynamic Programming COP	Considered	✓	✓	✓	Short-term
EcoTour [8]	Dijkstra's algorithm	Not considered	×	×	✓	Short-term
OVO Energy-Vehicle to Grid	OVO Green AI Technology	Considered	✓	✓	✓	Short-term
HEMS-Demand Side Manag. [9]	Single Knapsack Algorithm	Considered	✓	✓	×	Short-term
HEMS-Multiple Knapsack [10]	Multiple Knapsack-Ant Colony	Considered	×	×	✓	Long-term
HEMS-Multiple Users [11]	0-1 Knapsack-Genetic Algorithm	Not considered	×	×	×	Short-term
HEMS-Renewable Energy [12]	Binary Particle Swarm	Considered	✓	✓	✓	Short-term
IoT Meta-Control Firewall [13]	**Hill Climbing Algorithm**	**Considered**	✓	✓	✓	**Long-term**

a larger share of self-consumption and also reduce additional costs arising from the integration of photovoltaics. Information and Communications Technology (ICT) pioneer solutions and smart green planning systems are required in order to unleash the full potential lying within the transition from passive consumers to both active providers and consumers (i.e., prosumers). However, widespread adoption of self-consumption solutions may result in an unfair and unequal distribution of network charges and taxes. Therefore, future energy policies need to also deal with efficient cost reallocation [15].

Figure 1 shows how users can plan their home appliances based on their daily solar power production in order to consume energy more efficiently and consequently reduce both CO_2 emissions and electricity costs. The solid green color in the plot indicates the solar energy produced and red dashed color shows the energy supplied from the grid. Consequently, minimizing the CO_2 pollution in spaces where the human is active (e.g., houses, offices, etc., in which people spend 80-90% of their time) can positively impact climate change.

The efficient adaption of natural renewable sources, such as wind, solar, vibration, and thermal, into the IoT infrastructure is very encouraging, but challenging at the same time, as it can potentially be time consuming or difficult to integrate the requisite solution due to the surge of instantaneous power production in vendor-specific devices. Furthermore, it may not be always feasible to provide devices with continuous power using natural renewable sources, that will lead to other issues such as interruptible power supply due to the transmitting combination of energy obtained from either the grid or batteries. Consequently, system-level solutions are needed that will be durable and resilient in the event of a power outage.

The work presented in this paper is focused on the exposition of numerous existing energy management systems and the emerging field of green planning systems for self-consumption of renewable energy. An overview of early solutions of smart energy systems that will potentially emerge is initially introduced. Emphasis was given at extending the intelligent use of renewable energy, which will give rise to new services and applications for a better quality of life. Further, we describe our IoT Meta-Control Firewall (IMCF) system [13], which aims to balance energy usage, comfort and CO_2 emissions while satisfying the users' Rule Automation Workflow (RAW) pipelines in a way that these do not collide with some pre-configured long-term goals. The aim and outcome of this article is to highlight the importance of the design and development of effective green computing architectures, the adaptation to natural renewable sources and that the power management optimization, scalability and complexity are some vital challenges that need to be conscientiously studied and addressed in the close future. In summary, in this paper we have the following contributions:

- We present, compare and discuss the emerging field of green planning systems for self-consumption of renewable energy in regards to prediction, monitoring, scheduling, energy-efficient operation and AI-enabled management.
- We overview the novelties of our developed IoT Meta-Control Firewall (IMCF) as a green planning system for smart homes.

The remaining of the article is organized as follows: Section 2 presents the background and other related work. Section 3 introduces our developed IMCF framework, its internal components, the AI-inspired algorithm and the system architecture, while Section 4 concludes the article along with several future challenges.

2 Green Planning Systems

In this section, we present various green planning systems and energy management applications in regards to predictions, monitoring, scheduling, energy-efficient operations and AI-enabled management. The first two columns of Table 1, present related systems and the adopted approach. The next columns refer to whether the user comfort, energy storage and renewable energy were considered in the research study, respectively. Column 6, refers to whether the proposed approach takes into consideration any user preferences, or if the system acts completely autonomous. Finally, column 7 emphasizes the long-term and short-term planning perspective of each work. Particular focus is given on Home Energy

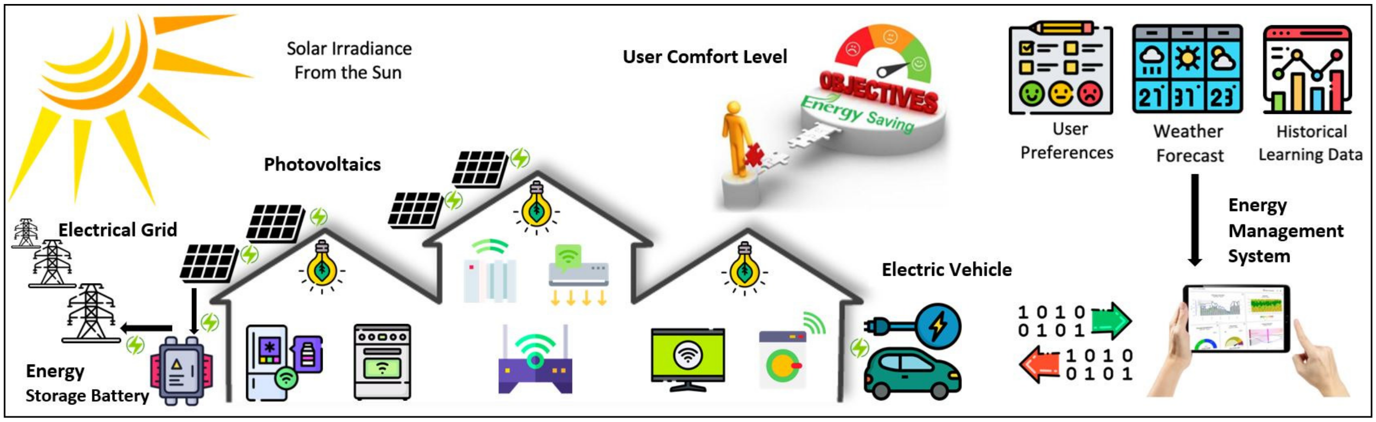

Fig. 2. An example of a green energy management system that makes use of photovoltaic technology in combination with residential energy storage and vehicle to grid technology considering user preferences, comfort levels, historical consumption patterns, and the weather forecast.

Management Systems (HEMS), since these expose a growing industry in the modern era of smart environments and smart grids (see Figure 2). Most systems consider user comfort with user preferences, few consider energy storage and renewable energy and only four consider the long-term perspective, where only one combines it with consumption of renewable energy.

2.1 Smart Home Energy Predictions & Monitoring Systems

In this subsection, a general overview on energy prediction of smart buildings is presented. Gemello [3], estimates a home's energy breakdown by comparing it to similar households with a hardware-based disaggregation approach. The Arup Smart Workplace[4], is a smart IoT desk that improves the occupants' satisfaction with the environment, health and productivity by personalizing the environment based on their monitored preferences. A deep latent generative model for energy disaggregation based on variational recurrent neural networks [4], accurately predicts energy consumption of appliances that consume less power and have no discernible repeating pattern. The latent variable abstractions help in achieving good prediction performance on previously unseen data.

GreenerBuildings[5], a project funded by the European Commission, aims at substantial energy savings in commercial and public buildings that involve highly dynamic patterns. It develops an integrated framework that uses energy-harvesting sensors to realize energy-aware adaptability, building-context and operator activity recognition, and embedded software for the coordination of hundreds of building-distributed intelligent devices. The project's methodological principles include thermodynamic building simulations and occupant-behavior, living-lab validations, and building-wide dense sensing of activity. Consequently, existing buildings will be retrofitted with an energy-aware framework, enabling the evaluation of theoretical and experimental findings in regards to energy-saving potentials while addressing user comfort.

2.2 Smart Heating, Ventilation, and Air Conditioning (HVAC) Scheduling

HVAC systems utilize more than 60% of the buildings' power consumption, and since this percentage is likely to rise in the future, it is crucial to optimize their energy performance and their effective operation. Buildings account approximately for 75% of the community's electricity, and about 41% of the community's overall power consumption, which is valued at $\approx$ $431.1 billion in the United States. With home automation intelligent apps and HVAC system incentives, energy savings of up to 40% can be realized [5]. Smart thermostats can have a significant impact on users' energy consumption when it comes to residential automation techniques. In 2012, approximately 1.5 million smart automation systems for households were setup in the United States. The Integer Linear Programming for Smart Scheduling (ILPSS), is a solution for improving the duty cycle of the HVAC equipment, optimizes energy consumption and keeps the temperature within the users' comfort zone [6].

2.3 Smart Thermostats

The Nest Learning Thermostat[6] is a self-learning and programmable Wi-Fi-enabled thermostat that optimizes heating and cooling to efficiently conserve energy. It learns users' behavior patterns and preferred temperatures over the course of a few days and then creates a timetable for their HVAC equipment. In households with central air conditioning, Nest Thermostat savings are shown to be equal to 10% -12% of heating usage, while electric savings are equal to about 15% of cooling usage. Another smart thermostat with similar functionalities is the Ecobee3[7]; its greatest feature is a remote sensor, which detects temperature and movement in other rooms and automatically re-programs. According to an analysis conducted in 2013 in the United States, Ecobee3 users saved up to 23% on their heating and cooling bills. These types of thermostats, however, do not allow individuals to

4. Arup Smart Workplace, URL: https://tinyurl.com/y5cz645c
5. GreenerBuildings, URL: https://cordis.europa.eu/project/id/258888
6. Google Nest Learning Thermostat, URL: https://tinyurl.com/2w9k5n4p
7. Ecobee3, URL: https://tinyurl.com/kz3nun

adjust their comfort choices and meet their long-term energy planning goals considering at the same time the carbon dioxide emissions. Furthermore, they require the collection of learning data from operators, which may introduce privacy concerns.

2.4 Photovoltaic Home Energy Management

Residential photovoltaic (PV) installations are a very promising option to locally generate and consume cost-effective and sustainable energy. The process of balancing the mismatch between demand and supply of energy is a crucial technical matter related to the integration of renewable energy systems into local electricity networks. The matching of renewable energy with residential consumption can be accomplished through multiple ways such as: (i) vehicle to grid technologies; (ii) residential storage systems, like batteries, in combination with PV systems; or (iii) by using community-based storage systems.

The SMA Sunny Home Manager[8] (HM) controllers monitor power flows, specifically the generation of AC power by inverters and the consumption of AC electricity by households using an energy meter. Then, HM handles the energy consumption workloads respectively (e.g., plans the operation of a smart car charger or a washing machine so that solar power self-consumption is optimized). This is accomplished through the use of its open Simple Energy Management Protocol (SEMP) or the industry-wide adopted EEBUS[9] protocols via its KEO reference implementation. These protocols, on the other hand, are designed for load management inside smart environments rather than assisting individuals meet long-term energy (power consumption) goals and restricting CO_2 emissions.

In [7], an energy management edge-based system is proposed, that allows electricity cost reduction, saves budgets on building up the infrastructure and also takes into account user preferences. A load shifting approach has been employed on an edge gadget, and solar power is integrated into a home energy system as a cost effective technique. A location-aware non-intrusive load monitoring (NILM) algorithm was used to attain energy disaggregation at different periods throughout the day, lowering capital investment on hardware equipment like smart meters and sensors.

2.5 Smart-Green Mobility

Eco-routing is a smart and a very efficient method to reduce automobile fuel consumption and thus greenhouse gas (GHG) emissions. EcoTour is an application that annotates an OpenStreetMap representation of a road network using eco-weights based on fuel consumption data and global navigation satellite system, collected from automobiles traveling in the road network, thus enabling ecorouting. It provides the fastest route, the shortest route, and the eco-route, additionally to various other statistics for each route [8]. Moreover, OVO Energy-Vehicle to Grid[10] is a system that can significantly reduce environmental impact. Fossil fuel power stations are firing up to supply appliances across the country with energy. The OVO's "vehicle to grid charger" knows that user's electric vehicle's giant battery has some charge left over, so instead of buying energy, it decides to sell it at times where the value and demand are high. In that way, users are actually providing power to the grid. On the other hand, when energy is cheaper and more likely to be generated from renewables, then OVO charges up user's electric vehicle. Consequently, OVO users can save enough to charge their cars for free.

8. SMA Sunny Home Manager, URL: https://tinyurl.com/9fj4uj83
9. EEBUS, URL: https://www.eebus.org/technology/
10. OVO Energy-Vehicle to Grid, URL: https://tinyurl.com/9m9d4bnk

2.6 AI-Enabled Energy Management Systems

Researchers incorporate different algorithms for efficient power management. The research approach in [9], focuses on a HEMS coupled with Renewable Energy Sources for efficient demand side management in smart grids. A single Knapsack method was used to obtain an energy minimization cost model, based on the total consumed energy of appliances. Furthermore in [10], the authors kept the total power consumption of each household device below a pre-configured threshold with maximum possible benefit, by tackling the matter for each scheduled hour of a day. The ant colony optimization approach was used to solve multiple knapsack problems, allowing efficient appliances scheduling. A similar work was published in [11], where the authors mathematically formulated the load scheduling problem as a knapsack challenge, which was then solved using a Genetic Algorithm (GA). Evolutionary algorithms, such as GA, have the ability to search the objective space of complicated problems more efficiently in the sake of utilizing more computational resources compared to other mathematical methods.

An optimal appliance usage strategy has been introduced by [12], based on binary particle swarm algorithm, taking into consideration the interests of energy suppliers, customers, and renewable resources. The proposed system satisfies the user's requirement for the least tariff as well as the demand for energy shifting or reduction, allowing for peak load shaving and thus reducing the household payments significantly. Furthermore, our in-house developed innovative system, coined IoT Meta-Control Firewall (IMCF) [13], aims to schedule comfort preferences of users in smart buildings (expressed in the form of so called Rule Automation Workflows - RAW), and meet various short and long term energy objectives. A more detailed analysis of IMCF algorithm and system architecture follows in Section 3.

3 THE IOT META-CONTROL FIREWALL (IMCF)

The importance of self-consumption has been highlighted by the advancement of renewable energy infrastructure in smart environments. The comfort preferences of users are frequently specified in the manner of Rule Automation Workflows (RAW), which are software rules dictating how and when IoT gadgets must function to allow operators to meet their desired levels of comfort, as opposed to self-consumption directives. We have proposed the IoT Meta-Control Firewall (IMCF) [13], which aims to bridge this gap and strike a

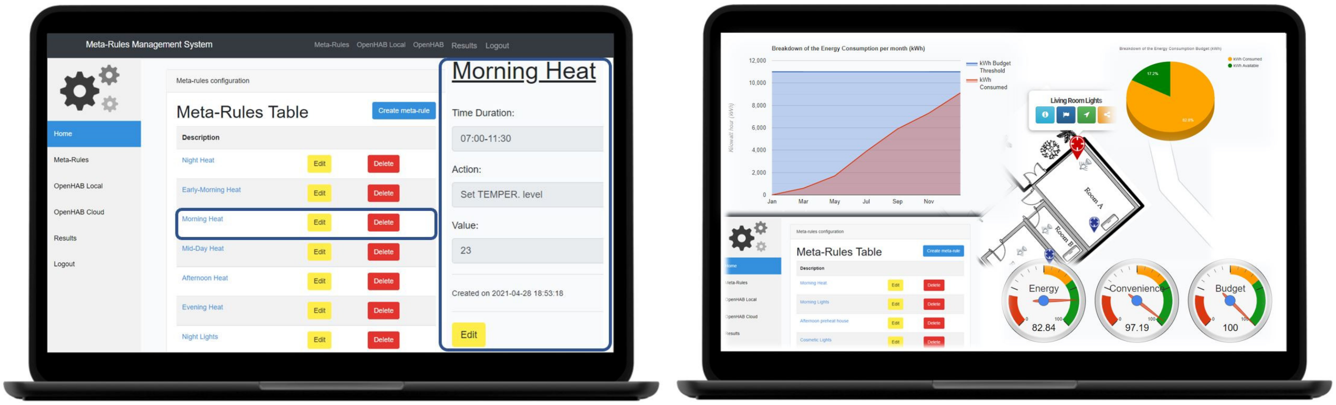

Fig. 3. (left) IMCF Graphical User Interface integrated in OpenHAB; (right) Dashboard for smart environment integrated with Anyplace Viewer and Meta-Rule-Table Configurator

balance between power usage, comfort and CO_2 emissions in satisfying the users' RAW pipelines so that these do not collide with the pre-configured long-term goals. Particularly, our framework incorporates two internal components: (i) the Amortization Plan (AP) algorithm, which is responsible for calculating the user's maximum energy budget per computed time frame; and (ii) the Energy Planner (EP) algorithm, which generates an energy-efficient plan considering users' comfort levels.

In IMCF, a user-operator starts out by setting an Energy Consumption Profile (ECP), and a vector of RAW rules, named Meta-Rule Table (MRT). The high-level goal is to discover which MRT rules should be dropped in order for the user to stay within the pre-configured energy budget based on the ECP history. To this end, a smart search algorithm is employed, which traverses an exponentially huge search space of multiple combinations, quickly identifying the rules that should be discarded.

3.1 System Architecture

Our system architecture comprises of a full-fledge local controller developed in openHAB's[11] internal stack, which is an intelligent home automation framework, and IMCF, which is a green Internet-based management system.

Local Controller: is a software based in java installed on a device, running on the user's local network. The *Local Controller* is communicating directly with the IoT appliances to instruct them according to the user configured preferences. A user-operator will normally download the openHAB application, for Android or iOS, and use the *Local Controller* to interact with the IoT devices. In case that a user's application is out of the smart space bounds, the Network Address Translation and network firewall will prevent the user from communicating with the controller. As such, the user's application establishes a connection with the *Cloud Controller*, which is a public Internet server capable of communicating and controlling the *Local Controller* remotely.

The IMCF Component: we have implemented a software extension to the *Local Controller* in order to enable the adaptation of users' comfort preferences to meet the long-term energy planning goals. Its design enables the encapsulation of the Energy Planner (EP) algorithm implementation but also the GUI and storage as necessary to enable interaction with the system by the user. The EP, which is developed as a java library, retrieves user configurations from a MariaDB local persistency layer. The user populates the storage layer with the application, which has been set up in such a way that it integrates seamlessly the MRT rule definition procedure over a web-based GUI (see Figure 3). The Laravel PHP web framework is used to write the GUI code. The GUI code execution relies on a web-server supporting PHP while for the IMCF EP library a cron job daemon is assumed that reliably invokes the Energy Planning in fixed time intervals. In the event that devices must be switched on or off, the IMCF system uses "Binding-mode" or "Extended mode".

11. OpenHAB, https://openhab.org

3.2 The IMCF Algorithm

The IMCF algorithm [13] consists of: (i) the *Amortization Plan (AP)*; and the (ii) the *Energy Plan (EP)*. The maximum energy budget constraint (coined E_p) is determined by the amortization plan using a pre-defined amortization formula. Then an AI procedure is executed every t seconds (e.g., yearly, monthly, daily, hourly preference) over a time period p (i.e., the execution's duration), where N is the set of all meta-rules and D denotes the number IoT devices in total, to generate an energy plan solution s^* for minimizing the Convenience Error

$$\min F_{CE} = \sum_{k=1}^{t} \left(\frac{1}{N} \sum_{i=1}^{N} \sum_{j=1}^{D} ce_j(MR_i)\right), \quad (1)$$

where j is the device, and ce_j is the difference between the desired output value $\Omega_i^j \in \Re$ of a rule configured by a user (temperature or level of light intensity) and the actual value $O_i^j \in \Re$ set by the controller, given by: $ce = |\Omega_i^j| - |O_i^j|$. Subject to satisfying the Energy Consumption $F_E(s^*) \leq E_p$, where:

$$F_E = \sum_{k=1}^{t} \left(\frac{1}{N} \sum_{i=1}^{N} \sum_{j=1}^{D} e_j(MR_i)\right), \quad (2)$$

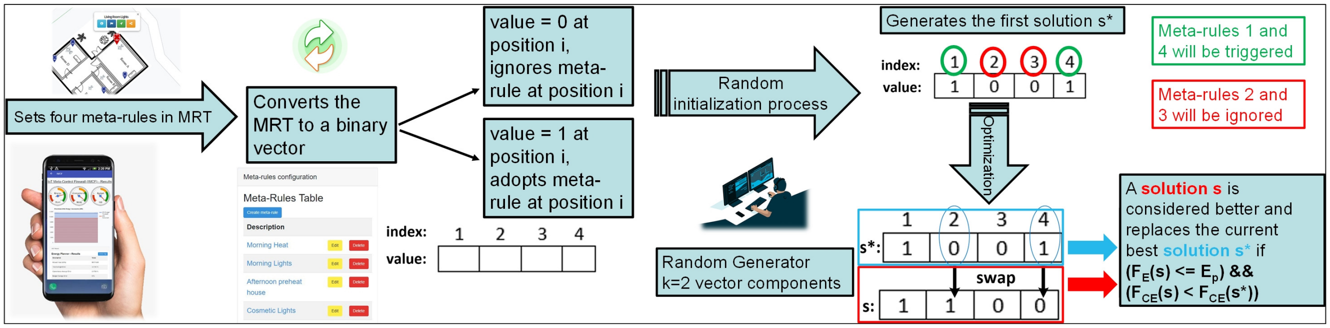

Fig. 4. Execution scenario of the IMCF framework where a user configures numerous meta-rules in MRT. The Energy Planner utilizes the hill climbing approach to optimize user comfort and energy consumption.

MR_i is the meta-rule, e_j is the energy consumption, and E_p denotes the total available energy budget for the entire period p in which the algorithm is executed.

Amortization Plan (AP): The initial execution of $AP()$ subroutine calculates the energy budget constraint E_p, while considering a monthly residence *Energy Consumption Profile* ECP. There are numerous amortization approaches that can be applied, like Linear Amortization Formula, Balloon Linear Amortization Formula, and ECP-based Amortization Formula. Our approach can be integrated easily in smart actuation platforms, since it does not depend upon training data and only requires a MRT preference profile.

Energy Plan (EP): An energy plan solution is a vector $s =< s_1, \ldots, s_N >$. A vector element s_i denotes a meta-rule in the MRT, where $s_i = 0$ means that at position i of MRT table the meta-rule is ignored, and $s_i = 1$ means at position i the meta-rule is adopted. We have applied a hill-climbing algorithm, an iterative local search heuristic, which does not require a target function (e.g., like A*), does not require a learning history (such as respective Machine Learning methods), and is straightforward to be developed in a resource-constraint setting like smart local controllers (e.g., Raspberry). An initial solution s^* is generated at the beginning of the local search heuristic, which specifies the initial state of the algorithm either randomly or deterministically. For local optimization with neighborhoods that involve changing up to k components of the solution, a hill-climbing local search heuristic is used, also known as k-opt. The performance metrics F_{CE} and F_E are used to evaluate each solution s (see Figure 4). A solution s is considered to be better and replaces the existing best solution s^* if $(F_E(s) \leq E_p)$ && $(F_{CE}(s) < F_{CE}(s^*))$. When τ_{max} iterations are completed, then the energy planner stops. Alternatively, the algorithm can iterate until $\nexists s | F_{CE}(s) < F_{CE}(s^*)$.

We claim that the consumption of power by utilizing intelligent approaches (i.e., green IoT actuations) can significantly contribute to the ICT environmental impact, allowing people to improve living conditions and sustainability, while respecting the ecosystem and meeting the United Nations Climate Change - Paris Agreement[12] targets.

12. UNFCCC, URL: https://tinyurl.com/5aamruum

4 Future Challenges and Conclusion

There are several challenges to be tackled before green planning systems solely integrate into our society. In this section, we present various major challenges related to green management frameworks followed by our conclusion. These challenges will channelize directions for future research studies.

Interoperability: Various communication technologies may be adopted by different vendors, users and utility companies. Thus, it becomes essential to satisfy interoperability and compatibility so that numerous heterogeneous technologies can coexist in green management frameworks assisting that way the seamless integration of different systems.

Scalability: A system whose performance increases with proportional hardware addition is said to be a scalable system. Green planning systems involve huge numbers of devices and users, and these numbers will keep growing drastically, hence scalability becomes an issue. Scalability tests and experiments conducted on small scale environments may not be able to cope when used with an extensive amount of devices in a realistic situation.

Interdisciplinary: Green planning systems involve various stakeholders (organizations, societies, technologies, devices, and frameworks). Hence, the interdisciplinary nature of this research area gives rise to various challenges, such as the integration of energy frameworks with actuation, control, security, renewable sources, weather forecast, and peak load schemes.

Security and Privacy: The interconnection among various systems, devices or networks, raises security and privacy concerns. The threat of cyber vulnerabilities for future green management frameworks is a crucial matter that needs to be addressed. The security matters may include electricity theft, accessing smart metering data in an unauthorized fashion, attacking energy storage facilities to affect power continuity, or accessing smart home appliances controlled by an unauthorized individual. A person with malicious intents could access and leak out sensible information.

Power Fluctuations: Natural renewable sources cannot always provide continuous power. Thus, the sudden rise or fall of electrical power due to transmitting combination of energy obtained from either the grid, photovoltaic modules, or batteries will lead to problems. Therefore, resilient and durable green management frameworks should be able to efficiently handle power fluctuations and outage events.

In this paper, we overviewed the emerging field of green planning systems, which belongs to a new type of Internet-based technology that aims to use computing resources efficiently in order to reduce energy consumption and CO_2 emissions. A detailed analysis and comparison of the existing energy management frameworks and AI algorithms is presented, showing that the field requires attention in respect to long-term planning perspective, both in the academic and industrial sectors. The intelligent self-consumption of renewable energy will assist in reducing peak loads and electricity costs, as well as minimizing GHG emissions, and Green Planning systems have an instrumental role in this process. The IMCF algorithm, components, and architecture satisfy long-term energy objectives while achieving high user comfort and economic advantages. The future of green planning systems exposes various important challenges that need to be tackled, such as interoperability, scalability, interdisciplinarity, security and privacy. In conclusion, it is essential to allocate more resources and efforts for developing more sustainable frameworks and promoting environmental awareness in the future, while considering complexity with multiple objectives and constraints of real-life situations.

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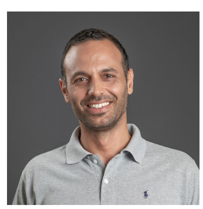

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