Envisioning Cloud of Energy

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***Abstract*—Energy and Information and Communication Technology (ICT), as two driving forces of the contemporary life, are reshaping themselves based on ubiquitous society architecture to improve their service quality. Within the reforming process, integration of the two systems can contribute to a greener ubiquitous society by equipping them with the concept of energy conservativeness, and leveraging renewable energy sources. In this paper we outline the idea of Cloud of Energy (CoE) which fosters the adoption of green energy and green cloud by integrating these two systems. CoE introduces an integrated framework of everything as a service to facilitate the service exchange, not only across the computing and electricity grid hierarchy, but also among them via an economic middleware.**

I. Introduction

As carbon footprint rate rises in recent years, and is predicted that the global carbon emission will reach 1430 megatonnes by 2020 [1], being energy efficient and moving toward green energy sources are essential for environmental sustainability. Information and Communication Technology (ICT) plays a leading role in this context by its potential for providing a large scale, real time, controller to improve decision making and developing environmental information systems [2]. Moreover, investments in energy saving technologies are compensated financially, particularly when carbon tax is applied to the energy price. However, this ICT infrastructure itself is a source of energy consumption. For instance, cloud computing energy consumption will increase to 1,963 billion kWh by 2020 and the associated CO2 equivalent emissions of 1,034 megatonnes will be expected [1].

Therefore, green ICT and ICT for green need not be mutually exclusive, both are important and they complement each other [3]. Hence, the challenge for the future lies in synthesising, not only ICT for green, but also green ICT, to achieve a more sustainable service framework.

The electricity industry attempts to transform itself from a centralized, producer controlled network, to a more consumer interactive and decentralized one, via smart grid. Smart grid intends to achieve grid's full potential and prepares a cleaner and more efficient, reliable, resilient and responsive electric system. A smart grid system needs a large scale infrastructure for collecting and communicating data; likewise, it must have access to flexible, network-scattered computational power, network bandwidth, and storage capacity, due to the distributed nature of data sources.

Akin to smart grid, ubiquitous P2P society is a collaborative effort in which infrastructure and services are shared among several individuals and/or organizations forming a specific community with common concerns. Ubiquitous society envisions a world in which services are accessible from anywhere, anytime, by anyone and anything [4]. These goals are partially intersected with the cloud vision, which introduces pervasive service provisioning. Therefore, we name the ubiquitous P2P society as P2P-cloud.

Since Energy and ICT are two pillars of modern life that advance hand in hand, in line with the goals of ubiquitous society, in this paper, we propose a Cloud of Energy (CoE) system, which considers everything as a service (XaaS), as introduced in the idea of clouds [5], e.g. Infrastructure as a Service, Platform as a Service and Software as a Service. In tandem with this trend, Energy as a Service is added to the agenda in CoE. Smart grid and P2P-cloud are both large scale distributed systems involving vast sums of common specifications: self service, metered, elastic resources, multi-tenant, and access via the network are cases in point. Thus, CoE combines P2P-cloud, including sensors, commodity desktop machines and IoT boards, with the smart grid, to provide energy efficient services and also to contribute to the smart energy system's computing and communication platform.

There is a growing body of work centered on exploiting the cloud and peer to peer platforms for the smart grid computing [6]–[9]. In a cloud computing environment, flexible data centers offer scalable computing, storage and network resources to any Internet-enabled device on demand. Moreover, P2P-cloud can manage the massive amount of data from distributed sources of consumption, generation and network nodes. On the other hand, diverse energy sources of smart grid improve the availability, sustainability and environmental friendliness of the ubiquitous network society services.

The main contribution of this paper is introducing the CoE architecture as an integrated energy and computing platform, Section III. CoE aims to design a service framework that incentivies all range of service producers, offering services from computing to energy, in range of small prosumers to giant providers, to serve in a greener marketplace, through an economic middleware, outlined in Section III-B. We analyse the feasibility of the proposed architecture in Section IV.

II. Related Work

Integrating utilities and services in an energy aware ubiquitous system, we move toward a sustainable ubiquitous society. There are some studies [10] on how to leverage a Peer-to-Peer platform as the ICT infrastructure of Smart grid. For instance, the CoSSMic project [11] aims to develop the ICT tools needed to facilitate the sharing of renewable energy within a neighbourhood. Cisco also proposed the combined platform of fog and cloud computing for smart grid data processing [12]. P2P clouds [13] and ClouT [14] approached this issue in a more general view by targeting the Internet of Things enabled smart homes and cities. On the other hand, diverse renewable energy sources of smart grid elevate environmental friendliness of the cloud services [15], also energy based service pricing improves the fairness of pricing mechanism [16].

Ubiquitous network provides communication and computing infrastructure for smart grid. A perfect ubiquitous platform offers user enabled control mechanism that can involve users in the control of cloud enabled smart grid system [17]. This improves the efficiency of data analysis and movement, since smart grid control data analysis on time series data perfectly matches the parallel data analysis [12]. Data analysis algorithms can run on subsets of data, i.e. a subset of users' data chosen according to the locality property, stored on different machines, and aggregate them into the final result set through hierarchical, multi-level processing. As with the distributed storage, the distributed parallel processing is harnessing the network of commodity hardware, i.e. P2P-cloud platform, according to the computing and energy resources availability. Moreover, aggregation gives the possibility to anonymize data, which is a safe and secure way to retrieve business intelligence information to personalize the services without violating the end user privacy.

The reverse side of the coin is that smart grid can also provide various energy sources for cloud services. Charging according to the energy price, users are more concerned about the energy sources and prices [16]. Hence, we make a broad range of choices for the users via providing them with smart grid resource availability data. For instance, a metering mechanism is developed in [18] to track the cloud infrastructure input electricity cost payable to smart grid. This cost model aligns electricity pricing with the smart grid goals. In [15], cooperative virtual machine management of cloud users in a smart grid environment is introduced. In such an environment, the cloud users can cooperate to share the available computing resources in private cloud and public cloud to reduce the total cost.

Therefore, rolling out an integrated energy and computing platform, we can integrate ubiquitous society and smart grid platform to move toward a greener pervasive energy, communication and information systems not only in terms of smart grid, but also for the computer based services. Integration reinforces the sustainability in both systems, since it is tightly coupled with socio-economical approach which is improved toward collaboration in such an integrated system. Increasingly, an integrated system can exert the common sources and data which are required to be duplicated in two isolated system controllers.

The role of an integrated system which we call Cloud of Energy(CoE), as the deployer of sustainable ubiquitous society, rises the following questions:

- How can CoE contribute to the better use of renewable energy?
- How can CoE control a changing network topology with a huge number of distributed energy providers?
- How can CoE contribute to establish new services and solutions?
- How can it contribute to the smart grid marketplace?

In the next section, we outline CoE solution space that facilitates the mutual collaboration of ubiquitous society and smart grid systems by initiating an answer to the above questions.

III. Cloud of Energy

Smart grid aware ICT service provisioning can foster the idea of green ICT by better employment of energy sources. On the other hand, there are some endeavors to leverage ICT platform for smart grid communication and information subsystems. Besides, with the idea of Internet of Energy, Internet not only can serve as the communication infrastructure for the smart grid, but also the distributed mechanisms designed to manage the Internet, and tackle the administration issues, can inspire the solution space of smart grid challenges, which is called Internet thinking of smart grid [19]. All the same, the cloud is already proposed as the information subsystem for the smart grid, in the state of the art studies [6]–[9]. Previous work suggests also how P2P-cloud can be leveraged as the information subsystem at the smart micro-grid level [17].

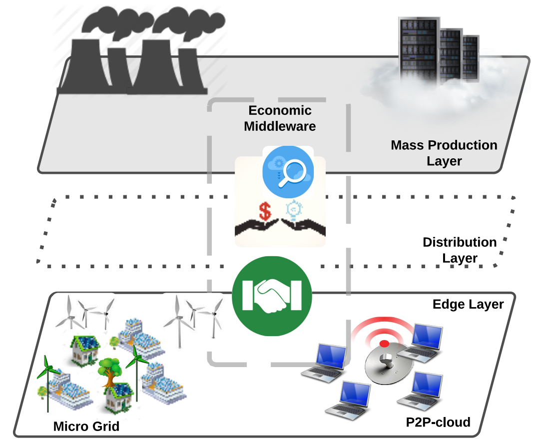


Fig. 1: CoE Architecture

Partly inspired by Internet of Things (IoT), Internet of Energy (IoE) [20] is about providing energy as a service in a more efficient way by dynamically adjusting resources to deliver energy at the lower cost and the higher quality possible in the context of smart grid.

In line with the idea of Internet of Energy, we define Cloud of Energy (CoE). CoE outlines how involving customers in future ubiquitous society-driven energy conservation efforts can both foster the adoption of green energy, as well as green cloud due to the increasing energy awareness of society. The rationale is to get users into the loop, not only to guide them how to use the services, but also to involve them directly in the whole cycle of control, production and provisioning of energy. Ubiquitous society makes it possible to combine informational support with fostering intrinsic motivation of users, all over the generation, provisioning and control stack by acquiring immediate feedback on society state.

Moreover, a large-scale distributed management system is required that can process huge amounts of event data and operate in real time. It should be able to manage the interface with infrastructures such as service market platforms that support the cooperation of various players. It, thus, helps to automatically balance highly fluctuating supply and demand, in a reliable and cost-effective manner. Relying on crowd sourcing [21] in a ubiquitous society, we can obtain needed services by soliciting contributions from the society rather than solely from traditional suppliers.

A. CoE Architecture

CoE is inspired by the idea of federating ubiquitous P2P network platform and the classic distributed data centers to form a multi-layer interactive architecture. CoE fulfils hierarchical control system goals in the integrated system of XaaS that supports both computing and energy service provisioning.

CoE offers establishing Virtual Power Plant (VPP) and Virtual Private Cloud (VPC) for each network vicinity through the local broker. VPP leverages existing grid networks to tailor electricity supply and demand services for a customer. VPP maximizes value for both the end user and the distribution utility using a set of software-based dynamic systems to deliver value in real time, and can react quickly to changing customer load conditions.

All the same, Virtual Private Cloud (VPC) is a cost-effective solution to expand the presence into the public cloud instead of expanding private infrastructure. With its pool of highly available compute, storage, and networking resources, VPC fits well in scenarios involving variable or bursting workloads, test and development, and next generation mobile applications.

In CoE, there is a pool of providers, i.e. energy and computing service providers, including prosumers in the edge layer, and mass producers in the higher layer. CoE layered architecture assures quality of service via improving resource availability in edge-layer by the support from the mass production layer. A layered architecture of CoE is illustrated in Figure 1. Horizontal layers represent a hierarchical division of the service providers. Prosumers, i.e. consumers and retail service producers, at the bottom layer constitute the edge layer locally under the concept of vicinity (as illustrated in Figure 2). Classic cloud service providers and mass energy providers are categorized as the mass service providers in the highest level. The lower layers promote energy efficiency in resources usage and the employment of greener sources of energy. Meanwhile, the higher levels can ensure resource availability and cope with power variations in edge-layer power output.

In the CoE architecture, hierarchical brokers are responsible for managing the market in different layers. These brokers are cross layer agents that are in charge of hosting auctions and providing feedback to the layers below and above, in the economic middleware, as demonstrated in Figure 2. In this architecture, there is a bidirectional information flow. While wholesale brokers are statically placed, local controller/broker agents can be dynamically placed in any prosumer location providing that the prosumer can obtain the computing and energy requirements for the broker. In broker placement the priority is with the source which has excess energy generated. To reinforce the fault tolerance of the distributed system, we store the data in distributed data storage accessible to all the prosumer agents in the vicinity if they have access to the token. Dynamic local controller placement contributes to the energy efficient data processing and movement, which is the key for a sustainable system.

B. Economic Middleware

An Economic Middleware acts as an interface to facilitate smart electricity and ubiquitous computing service trading. This middleware, as shown in Figure 2, includes the following components:

Energy Controller(EC): module existing in each prosumer side, which is able to predict and measure the energy consumption of each individual appliance at home. All EC units are connected to the energy provider through a communication infrastructure such as a community network [22].

Computing Controller(C2): in each prosumer of ubiquitous society plays the same role of EC for the computing services.

Local broker: further to hosting auctions is responsible for defining tax rate based on the bids it receives.
If the demand and supply do not match and the vicinity encounters resource scarcity, the broker decreases tax rate, through tax controller, to make the external resources more affordable for end users. Moreover, the broker should submit the bids for the higher level broker, to obtain the resources for excess demand of the vicinity. A bitcoin repository component is responsible to keep the bitcoin balance of the vicinity which is necessary for trading with mass production broker, in the outside world. Bitcoin [23] is an online payment system, in which trade parties can transact directly without the interference of any intermediary, through bitcoin.

Mass production broker: in charge of setting up auctions among different service providers for the demands submitted by the local brokers.

C. Agent Based CoE Service Composition

The CoE system, as illustrated in Figure 1, can be modeled with the concept of multi agents. Multi agent systems are the most suitable platform to model distributed collaborative systems requirements based on their properties and functionality, allowing them to implement intelligence in the smart grid control due to their social ability, flexibility, self-healing features and economic agent support [24].

a) Environment: In the CoE agent based model, we have nested environments through the hierarchy of the architecture, which amount to a set of producers and consumers, and brokers. Looking closer, prosumers make a rich, heterogeneous environment which is controlled by coordinators, in order to drive the prosumers behavior and represent the interest of a group of prosumers on the market.

b) Agents: In CoE, agents include prosumers, brokers in different levels, service providers and mass producers of electricity and cloud services. Prosumer agents produce services in the retail level and are the end users of the services, at the same time. Each prosumer is equipped with a cloud and electricity controller, to regulate and control its demand and supply.

Broker agents in different layers can decide what strategies to employ both on the market and prosumers. For that we can apply a Stackelberg game, which is a hierarchical game where players of this game are leaders and followers across the hierarchy. The Stackelberg leader is the wholesale market broker and the local brokers should follow its strategy in the market. However, each broker can run its own double auction mechanism to supply the demands locally. This property gives the authority to the autonomous local brokers to run their own strategy as long as it does not violate the wholesale market's framework. This promotes decentralization, better scalability and speed of adjustment to varying local conditions, while bounding global imbalances.

Utility and cloud service providers can trade the mass provider services on their behalf via the mass production broker.

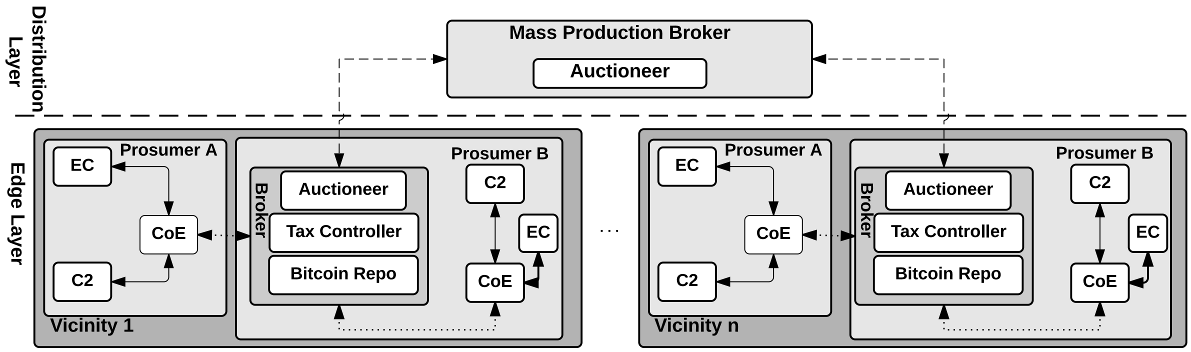


Fig. 2: Economic Middleware Architecture

c) Market Rules: Since energy and computer systems provide two different services, to integrate these two systems, in our market model, we need a metric that can measure the contribution of each service in an understandable scale for the other. Moreover, a universal metric facilitates the collaboration of the two systems. Virtual money seems to be an appropriate metric for this end. Defining local currency in the micro-grid-community level, we can incentivise the users to collaborate in the system by sharing the resources, i.e. energy and computing by earning credits. The idea behind defining a local currency is to drive and improve the coordination of users within a community, to promote the community among the others by elevating the value of their local currency against the other communities. Moreover, this mechanism helps in load balancing by changing the value of local currency, by allowing arbitration.

When local supply exceeds the local demand, the local broker can assign bitcoin [23] generation tasks to the prosumeres offering resources, in exchange of certain amount of local currency based credit in their account. Therefore, the **available resources are not effectively lost and can be re-acquired later from mass producers**, if supply is scarce in the vicinity. This is specially useful when the **energy powering the idle resources is green energy that is being under-utilized**. Thus, we can in a novel way, **effectively attempt at preserving resources and energy as effective reserves for later demand**.

Thus, local brokers, to provide resources from outside the vicinity, can only rely on some outside currency, i.e. the bitcoin generated in the vicinity when there are excess resources of electricity and computing in the vicinity (as an ideal universal replacement to any legal tender or precious metal). Afterwards, to deliver the service to the end user, local broker charges the users based on the community currency value equivalent to the amount of bitcoin and the associated conversion taxes.

Furthermore, to keep the system constraints, we define the exchange tax, which is an extra amount that should be drawn from the requesters credit due to service provisioning. To exemplify, communities geographically far will set higher exchange rates to assure the quality of service, i.e. reduced latency, lower transmission loss and more energy efficient service provisioning. Note that the Virtual money defined here deviates from the state of the art concept in terms that it does not necessarily follow the conservation property.

D. Challenges

Despite the synergies, there are relevant differences in cloud and smart grid services that should be taken into account in CoE planning. To design a comprehensive model for integration, we need to face the following challenges which stem from the natural differences of computing and energy systems.

- **Flow Management**: data flow management is way more flexible than energy flow management. In other words, we can encapsulate and label data easily, while it is not easy to route the electrons in the same way. Thus, implementing VPC is easier than developing a VPP.
- **Storable Services**: in smart grid, batteries can save energy. Therefore, energy service can be stored instead of instantaneously offered to the demands, while it is not possible to store the computing service (hence opportunistic bitcoin mining).
- **Stochastic behavior**: both systems are conforming to a stochastic behavior due to resource fluctuation and highly evolving topology, regarding origin of requests and availability of resources. In other words, due to the unpredictable collaboration paradigm of end users in the cloud, the system depicts a stochastic behavior. Likewise, in the smart grid energy provisioning system, we observe a stochastic behavior of renewable energy sources participating in the system, which is tightly coupled with the weather condition of each geographical region. However, the demand paradigm in the smart grid is more predictable than the cloud (more remarkable difference between peak and low usage). The electricity consumption pattern is almost fully determined in advance in the smart grid. The peak demand time is almost predictable in the grid system, while it is not as easy to foresee the demand pattern in a distributed computing environment.
- **Service Diversity**: the diversity of provided services in the computing platform is vaster than in the smart grid. This leads to the more complicated QoS and management mechanisms in the clouds.

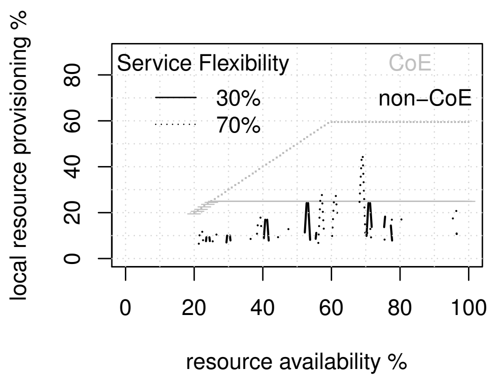


Fig. 3: Collaboration

In the next section we assess the feasibility of the proposed CoE system.

IV. Feasibility Assessment

We study the challenges of rolling out the CoE and elaborate the feasibility of the proposed architecture by answering several questions across this section.

A. Does bi-level architecture incentivize the collaboration?

Defining cost as the main incentive, CoE can improve the collaboration among the prosumers, through the credit earning mechanism. Figure 3 illustrates that more resources are provided within the vicinity in CoE compared to the random resource allocation mechanism.

Here, we only consider flexible service provisioning in the edge to assure the quality of service due to the uncertainty of renewable retail generators. Both electricity and computing services can be classified as rigid and flexible. While rigid service needs real time resource provisioning, flexible services can be scheduled for a later time, and is more flexible.

As illustrated in Figure 3, local resource provisioning depends on service flexibility, i.e. resilience to resource availability variation and resource availability in the vicinity. Here we studied two service models, with 30% and 70% flexibility (i.e., resilience to availability variation). The results show that the more resources available in the vicinity, the higher collaboration of prosumers occur in CoE compare to the random collaboration case. The collaboration in non-CoE case, however, is weekly correlated to the resource availability in the vicinity. Note that in CoE we do not consider the possibility of the inter-vicinity collaboration, since there is a significant transmission loss and quality of service degradation in this case.

Implication 1: Increasing the resource availability at the edge layer of the CoE should be considered as a priority to attain the smart grid objectives.

B. How much energy can be saved in CoE?

Figure 4-a depicts how much energy can be saved by smart service provisioning in CoE[1]. We see that some cloud services such as storage as a service in the P2P-cloud, i.e. edge layer, is more energy efficient compared to the data center case, while two other services are better to obtain via data centers in the higher layer. Therefore, combination of edge devices and data centers results in more energy efficient service providing that resources are allocated in an energy efficient manner. For this end, a framework is required to characterize the energy efficacy of each individual service in both platforms. A decision support system can help afterwards according to the analysis results.

Additionally, in Figure 4-b, the carbon emission of different services are compared. We assume that prosumers are equipped with solar roof tops, which emit 41 g/kWh and data centers equipped with 50% of renewable solar energy produced by solar PV at utility level and generate 48 g/kWh of CO_2 in average, and 50% of brown energy inducing 802 g/kWh of carbon footprint in an average case, according to [25]. This figure reveals the fact that, carbon emission as an incentive, besides energy consumption, may turn the table in more cases in favor of P2P-cloud, due to the lower emission rate of prosumer level renewable energy generators.

Implication 2: carbon emission rate is a better metric than energy consumption to quantify the efficacy of the system in fulfilling smart grid objectives.

C. How much cost will be saved?

In the state-of-the-art mechanisms, computer services are priced regardless of the energy consumption cost. However, energy aware service provisioning can save remarkably in the provider costs, since energy is a major part of dynamic price in the cloud service provisioning. Exerting CoE, we have a better chance of directing services to the appropriate layer of provisioning, and saving energy cost as a consequence.

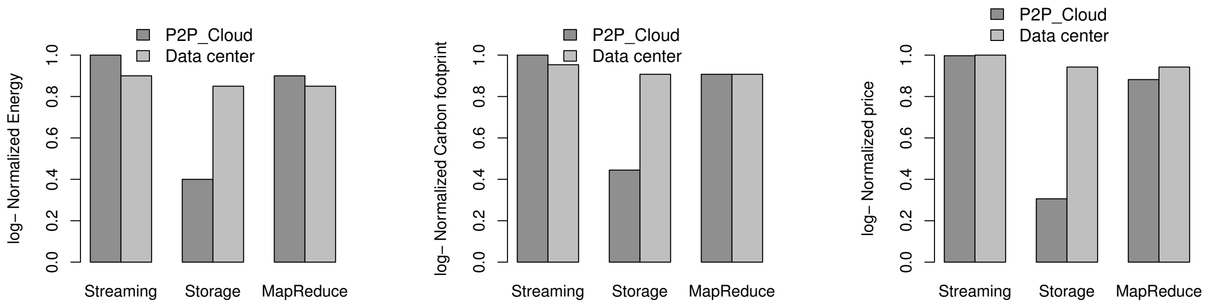
Besides, CoE provides an opportunity to share the infrastructure and data required in smart grid and cloud instead of duplicating the resources. Namely, in case of carbon based charging, finding a cheap energy source will be significantly important. In such a case, being renewable energy sources aware can help saving in dynamic cost. CoE as an integrated system will obtain the smart grid data to the brokers across the hierarchy, instead of duplicating this data in two separate systems of cloud and smart grid.

Figure 4-c illustrates the cost of energy in a carbon based energy pricing, which assigns the same price to all the energy sources and applies carbon taxes according to the carbon-footprint portion attributed to the electricity source. As shown in this figure, in all cases, P2P-cloud service provisioning leads to cost saving. Nevertheless, we should bear in mind that there is limited resource availability for local resource provisioning and the quality of service may not be obtained in local service providing.

D. Is implementation complexity warranted?

CoE reveals that integration facilitates a diverse range of service exchange. However, integration may incur more complexity to the economic layer in the system due to the different nature of each system such as uncertainty level, storablity, flow management complexity, etc. This added complexity should be warranted with the advantages of integration, e.g. more effective marketplace. To attain CoE goals, we need a robust economic model which can manage the demand and supply in a multi-variable marketplace.

[1]For the details of the experiment setup, interested readers may refer to INESC-ID Tec. Rep. 11/2015.



a) Energy consumption b) Carbon emission c) Price

Fig. 4: Energy, Carbon and Price of different services

Nonetheless, if we aim at greening the ICT while exerting ICT for green, CoE can be a good candidate to reduce carbon emission, save energy and cost as consequences of smart service provisioning.

V. Conclusion and Future Work

In this paper we introduced Cloud of Energy (CoE). CoE envisions the service provisioning framework of the future that provides everything as a service via an integrated cloud and smart electricity grid system in horizontal and vertical dimensions. CoE facilitates the resource management in each of smart grid and cloud through their hierarchy. It also expedites the horizontal integration of different services via their shared economic incentives. The economic layer acts as a middleware to translate a service in every concept, e.g. energy and computing, to the common incentive scale of money. Integration elevates the collaboration of diverse range of providers and consumers, requesting for different services. Moreover, an integrated system is more efficient and greener, since it avoids unnecessary redundancy in the common subsystems, such as shared data, computing and communication infrastructure, etc. Also the integration leads to greener system since it provides increased energy awareness. However, this is just the very first step in introducing the idea and still there are several open questions including CoE effect on consumption paradigm should be investigated more deeply.

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