Green Network Costs of 5G and Beyond, Expectations vs Reality

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***Abstract*—Generally, it has been taken for granted that green technology provides clean and cheap energy, but often without consideration of the costs. In fact, there are many trade offs concurrent with enabling such technology. Accordingly, this paper evaluates and compares the green energy oriented mobile networks with their traditional counterparts. It presents a mathematical model that helps in understanding the different variables which are necessary to advocate the green/renewable method over the traditional form or vice versa. This research shows that the cost efficiency (CE) of green networks can be relatively high, about twice that of the traditional, which is represented by cloud radio access network. Based on experimental data, this research shows that green technology requires more operational control than the traditional form to produce the same amount of power. With variant sites, cities, countries, geographical areas and equipment manufacturing characteristics, the proposed model can predict the futuristic total green network's trade-offs. By doing so, the service providers, investors or network vendors will be able to decide upon an appropriate balance between both types of networks.**

***Index Terms*—Green communications, Networks, models, modelling, cost, efficiency, Cloud-RAN.**

I. INTRODUCTION

Due to the continually increasing number of mobile network subscribers, more base stations are required to serve the higher volume of data rates. This is leading to rapidly growing energy demands and consequently, contributes to the energy crisis that is fostering global warming [1]. There are many techniques in the literature aimed at improving network capacity as well as spectral and energy efficiency, for example, heterogeneous networks, cognitive radio, energy harvesting [2], optimised resources allocations [3], cloudification [4], discontinuous transmission [5], and network function virtualisation [6]. These innovations can reduce the power consumption, yet they still have the traditional electricity forms in use, which increases the percentage of generated harmful emissions. Hence, the 5G enabling technologies must not only offer these bandwidth and energy savings, but all sectors of information communication technology (ICT), including cellular communications, have to shift from diesel to green energy based networks. Globally, there is an ambition to achieve 20% of energy needs from green energy by 2020, and for this reach 30% in 2035 [7]. This green evolution is required to replace the way that energy is consumed, and to conserve the environment by mitigating CO2 emission, which is the main cause of climate change and weather pollution [8]. We used the term green to indicate that the network's power supply is from green power generators or green farms, while the traditional network is powered using the electricity grid. Green or renewable technology means offering a system that is environment friendly, with the aim of utilising such a design being that the environment is not disturbed. Moreover, the current expectation of green sources is to bring enhancement in our daily life by providing the coming communication networks with required energy without depleting the earth's resources [9]. These goals, however, have to be achieved without tangible compromising in terms of changing the pattern of energy production and consumption. Generally, the literature has emphasised on using green energy sources instead of traditional grid supply to power the communications networks, but without evaluating the cost or trade offs underlying the usage of green method. Consequently, there are some operational challenges that are inevitable regarding green technologies, the majority of which are experimentally proven in this research, which can be briefly described as follows:

- The initial deployment cost is very high. However, retrieving this cost is certainly occurring after a time in terms of offering high revenue and power gain. This gain is due to less spending on electricity bills when using green energy over time in comparison to traditional grid. So, when exactly this gain is obtained? This issue requires a holistic modelling for the trade offs at the network system level.
- Green networks require very high expenses, including buying, installing and periodic maintenance to operationalise them. Hence, launching a green network can be practically daunting, unless the governments and high level institutions support this leap.
- Green networks represent a solution to reduce the enlarged harmful emissions that are resulted from burning fossil fuels. Hence, directing the scientific research of 5G systems towards green power is unavoidable.
- The geographical area required to implement a green project is generally larger than for traditional forms, which can render the rent very high in the context of the former.
- The generation process of green power is complex, and power production rates are low when compared to traditional electricity generation using simple fossil fuel generators.

The goal of this paper is to model these matters by providing a top-down system evaluation, with a view to gaining greater understanding and thus, be able to improve the performance of green network deployment. Accordingly, this paper addresses the challenges that stand in the way of fostering the escalation of green network development. It is expected that by exposing the inherent obstacles of green technology, further enhancements within this field can be achieved.

II. GREEN TECHNOLOGY PILLARS

There are several limitations that restrain the operation of green energy sources. These are divided into major and minor issues and are listed below.

1) **Power**: Fossil oriented generators consume about 1,500 litres of diesel per month, which costs the network operators about £25,000 each year. Generally, countries heavily rely on fossil fuel (coal, oil and natural gas) as a main sources of energy. Unfortunately, fossil fuel is non-renewable, meaning that it will ultimately be depleted, because it is a limited resource. As a result of its limitation, its price will be maximised over time. When the cost of energy is high, the cost efficiency (CE) (spectral efficiency (SE)/network cost) will be high too, which degrades the network performance [10]. Hence, renewable energy sources are the solution for the futuristic network architectures. Having said that, the amount of green power to be fed to the network site has to be sufficient. However, this condition is not valid all the time. One of the major challenges that is present with such technology is the ability to ensure appropriate amounts of power as needed. Moreover, the type of green power source has to fit with the area where the network is operated. For example, deploying solar cells in hot-weather areas and wind turbines in coastal ones. However, the success in selecting the proper type of green energy source that is suitable for a each type of geographical area, is the reason to offer a sufficient power to the network. If green energy is compared with the traditional grid, the power of the latter is constantly available regardless the type of geographical area.

2) **Cost**: The cost is a crucial issue that affects the shifting from traditional to green power. At the starting point, the cost of buying, deploying and maintaining the green equipment is higher than traditional. Nevertheless, this cost will fall over time as the prices of green devices are decreasing, which bodes well green technology in the long term.

3) **Environment**: Reducing CO2 emissions to deliver a cleaner environment and to combat climate change is now a global challenge. Renewable energy is considered clean as it does not cause environmental pollution. Globally, in 2010, the ICT sector contributed to about 2-3% of total green house gases emission [11], and this is expected to reach 4% by 2020. Only the mobile sector is responsible for 0.2% emission in 2010, up to 0.4% expected in 2020. This rising in the amount of harmful emissions is due to an increase in the amount of consumed power. However, the green energy sources also have deleterious impact on the environment, for example, using large amounts of acid-oriented batteries can result in harmful radiation when they are disposed and wind turbines might slay birds and block the ships movement. Moreover, solar cells take up vast amounts of space and large amount of electronics, yet, insignificant amount of power is generated.

4) **Maintenance**: The maintenance cost of green sources is noticeably higher than traditional sources due to higher utilised areas. In addition, the maintenance of green sources is generally intractable, for example, solar panels utilise huge areas, so do the wind turbines in rural areas, while the water based turbines implicate complex maintenance scheme, and so on.

5) **Reliability**: To operate a mobile base station, a specific amount of power has to be consumed. If the station is fully dependent/fed using green power, this source has to be constantly able to generate the required power. As the green energy is totally dynamic and based on weather/nature [12], this represents a definitive matter in terms of reliability and scalability of green energy. Hydro generators are based on rain, whilst wind turbines require consistent wind and solar panels need a sufficient amount of sun and clear sky. When these conditions are minimised, the capacity of generating the electricity becomes inconsistent and unpredictable. Furthermore, what is the probability of failure of the green source? What is the backup plan? The break down issue can be serious problem for rural/suburban sites, where there is total dependence on green sources and no hybrid (traditional-green) mode of operation is adopted. At the same time, depending on green energy in these types of sites can offer a solution, as deploying transmission lines is burdensome.

6) **Economy**: Since a large number of green energy projects are based away from the centres of cities, this can bring economic benefits to such areas for workers people living nearby, who have difficulty obtaining employment. Furthermore, the existence of green sources in such areas simplifies the process of transferring the energy to the network sites, as such, reduces the transmission lines' distances and relieves their maintenance cost. In contrary, transferring the traditional energy from city centre to the rural areas imposes an enlarged transmission losses and sophisticated management.

7) **Efficiency**: Green technology is relatively new on the market, meaning that it still lacks the guaranteed efficiency. This can deter the investors putting their money into green energy projects, as they cannot be certain of securing a quick return.

8) **CAPEX and OPEX**: Green projects require more geographical space than a simple traditional fossil based generator to produce the same amount of energy [12]. For example, a solar panel 65 inches long and 39 inches width with 20% efficiency, can produce about 250W of power, enough to operate only five light bulbs, each with 50W power consumption. To produce 500W, the area dimensions are doubled, and so on. Eventually, the required area to produce sufficient green power to the network site is huge, which magnifies the required capital (CAPEX) and operational (OPEX) expenditures. On the other hand, a simply designed and compact fossil fuel generator can easily produce up to 12,000W.

When taking all of the above into account, the case of adopting hybrid systems would appear to be more reliable, that is, the network could operate using traditional energy and green energy when it is available. If the service providers or network operators have a tool for calculating the power cost for traditional and green energy in a given area, a decision can be made quickly whether it is worth to going green, hybrid or completely traditional in terms of energy provision. In addition, for a given network data, the proposed model can predict when the high initial cost of green energy can be recovered. Subsequently, it shows how much power gain is obtained due to reducing the cost of green energy and increasing the cost of traditional energy over time. The proposed model in this paper can also help understanding how the different parameters that affect the green technology influence each other over time. Concurrently, the model indicates the most effective parameters within the green networks development. Whilst we have used solar panels in our experimentation, the presented model can be generalised for any type of green energy source. Moreover, a cloud radio access network is adopted as our case study to evaluate its CE, this being the ratio of spectral efficiency to the network cost.

III. RELATED WORK

In [13], a framework presents four major pillars that affect the usage of green technology, these being the: cost of deployment-PC trade off; PC-bandwidth (BW) trade off; PC-end to end trade off; and the spectral efficiency (SE)-energy efficiency trade off. Unfortunately, there was no mathematical model to describe how these parameters influence each other, neither was it indicated when green technology is advocated in favour of traditional forms. In [14], a heterogeneous network is powered using green energy, with the cost and CO2 emission savings being measured. However, this work has no realistic comparison for the trade offs with the traditional power sources. Similar shortage limitation can be found in [15], but detailed assumptions are provided regarding the number of base stations and traffic profile, using photovoltaic panels as the source for green power. In [7], a management and economy model is focused on showing that renewable energy projects with top management can have a significant impact on green technology in organisations. Unfortunately, this study was limited in terms of the number of green influencing pillars and only covered a specific area. The authors of [16] investigated the case of hybrid cloud radio access network, when the UE is powered by both sources of energy: green and traditional grid. However, the stochastic drawback of green energy was not tested. Work in [17], considered the energy consumption rate, this being the ratio between the maximum power and data throughput, to evaluate the energy efficiency; however, there was no probing for the imposed trade offs. In [18], the ratio between the number of green network subscribers and the power consumption (Subscribers/W) was evaluated. In [19], the deployment efficiency (bits/sec/cost) was measured to characterise energy efficiency of het-net deployment, i.e. the ratio of network capacity and deployment cost over one year. This work dealt with a traditional network without consideration of a green one.

In general, the studies that included evaluating the cost of green networks are rare because a real time green system experiment is required to calculate the actual cost [20], that is required to build a mathematical model. Measuring CE is a very important metric in futuristic network design as it holds the cost factor that decides how costly is the network deployment and services, that is directly affecting the spending of network subscribers. Hence, it is not logical to build an efficient system that is expensive. Many green projects have been launched in recent years to investigate the problem of energy efficiency, including: EARTH, Green IT, GreenTouch, OPERA-Net, GREEN-T, Cool Silicon Cluster, GreenGrid, Green500 and so on. These works have demonstrated the energy saving techniques, such as optimising 4G holistic power efficiency [21], yet, fully powering these projects using green energy is not tested. It is worth mentioning that most of the literature used the word 'Green' to reflect on the saving of their novel and innovative proposals, algorithms or techniques in view of energy, bandwidth, cost, spectral and energy efficiencies. However, it does not mean that a green power supply has actually been used [22], [23].

IV. GREEN COST MODELLING

The proposed model included several pillars that are fundamentals when evaluating green networks, these being as follows:

1) Power sufficiency: the sufficiency (S) of generated green power (P_g) can be defined as a condition that, if it holds true, it guarantees P_g is also true. Practically, this refers to the ability of the green source of energy to provide a sufficient power to the network in the next period of discrete time (n), where the total time of the operation $(t = \sum_{n=0}^{N-1} n)$, and N denotes the total number of time instants. The rule of succession has been used to represent this conditional probability. The probability that the source of power is sufficiently able to generate power (GP) increases with the number of discrete time n, this time on which, the source was successful to empower so far. Assuming S is distributed uniformly over $[0, 1]$ interval, then this sufficiency probability $S[GP|G\ n\ times]$ is given by:

$$S[GP|G\ n\ times] = \frac{\int_0^1 S^{n+1} dS}{\int_0^1 S^n dS} = \frac{n+1}{n+2} \tag{1}$$

This formula indicates that the greater number of past generated power, as represented by n, the higher probability a power will be generated in the next moment of time $(n + 1)$.

2) Reliability: the easiest way to assess this is by considering the failure rate. This can be taken as that components fail to operate after a time and is represented by the number of faults/time(t). Opposite to failure, is the reliability $(R(t))$. The reliability can be defined as the probability a component will not fail during the interval $(0, t)$. If the failure $F(t)$ is found, then the opposite, the reliability $(R(t))$ can also be known and is modelled as:

$$R(t) = 1 - F(t) \tag{2}$$

Moreover, since the green sites are mostly established far from cities, there will be extra losses in the transmission lines (l_c) in comparison with traditional grid based networks. This cost can be added to the above formula, which produces:

$$R(t) = 1 - F(t) - l_c \tag{3}$$

3) Economy: The economy factor of green network is assessed using four main considerations: jobs offering (J), establishing new business for investors (I), ambiguousness factor (i) and equipment prices (Y). In comparison to grid based networks, the first two factors are all benefits as they

impose offering new jobs and bringing more investments to the community/economy. Hence, the effect of these factors on the proposed model are maximised over time (t). Since green technology is new to the market compared to the traditional, an ambiguousness factor (i) is assumed to describe the risk of investing in green business, this factor impacts negatively against the green case.

However, to model jobs offering, it was described as $\frac{dJ}{dt} = \alpha J$, that is the change in jobs J with respect to the time t. When solving this equation, it produces $J(t) = J_{int}e^{\alpha t}$, where J_{int} represents the jobs offering at $t = 0$, namely, those before launching the project, and α denotes the increasing constant of the number of jobs. This constant is responsible for depicting the weight of jobs increasing over time. We have used the exponential expression to model most of the factors within this work because of the following reasons: (i) its behaviour can be as slow as linear, or rapid as exponential at the same time, if the constant α approaches 0, the model tend to be linear rather than exponential and, (ii) it offers an initial value to indicate the starting point of the model's attitude. This value is very important for the model to describe its behaviour at ($t = 0$), and finally (iii) in contrary to linear model, the exponential model prevents the behaviour to fall or rise to zero value even when the constant α is zero. For example, the prices of solar panels are much cheaper over time, but they are non zero prices. We have used the same style to model the investment factor (I) that increases by time (t), i.e.$\frac{dI}{dt} = \beta I$, solving this equation produces $I(t) = I_{int}e^{\beta t}$, where I_{int} denotes the initial investment level and β is a constant that describes the increasing in investment over time. On the other side, the ambiguousness factor (i) decreases by time as the investors will be more familiar with green technology in the future. It was produced as $i(t) = i_{int}e^{-\sigma t}$, where i_{int} indicates the initial ambiguousness before deploying the technology and σ is a constant that represents the decreasing in ambiguousness factor over time.

The prices of green equipment can play an additional role within this modelling. In our experiment we have used batteries and solar panels. The prices of solar panels drop from £250/W in 1956, to £27/W in 1980, then to £2/W in 2009, down to £0.2/W in our experiment. This dramatic fall in the prices surely advocates to using green technologies. It is clear that this relation is inversely exponential, i.e. dropping from very high price to a very low one. As the final price is very low and hence, can only be further reduced by a minimal amount. The modelling of these expenses must incorporate exponential behaviour, for linear modelling would allow for an unrealistic zero price. Accordingly, $\frac{\partial Y}{\partial t} = -\iota Y$, with the solution of this equation yielding $Y(t) = Y_{int}e^{-\iota Y}$, where Y_{int} represents the initial price of batteries and panels, whilst ι is the decreasing constant of the prices over time. Subsequently, the economy factor as a function of time ($Ec(t)$) can be formulated as the combination of all these factors, as follows:

$$Ec(t) = J_{int}e^{\alpha t} + I_{int}e^{\beta t} + i_{int}e^{-\sigma t} + Y_{int}e^{-\iota Y} \quad (4)$$

4) CAPEX and OPEX: these factors are significantly influenced by the size of area that is required for rent, for example, when using solar panels, the more utilised area, the more electricity will be generated. Generally speaking, this logic always holds true while dealing with different types of green energy sources. If we assume (A) is the area, the rent cost is (Rnt), which increases linearly with A and then, the rent cost can be given as $Rnt = \theta \times A$, where θ is the increasing linear constant. Moreover, the maintenance cost (M_c) is two fold, first increasing linearly with A, i.e. ($M_c = \epsilon \times A$) and second, there is a synchronised periodic maintenance (M_p). Hence, the overall maintenance (M) can be modelled as ($M = M_c \times M_p$), where (ϵ) is the increasing constant of the maintenance over unit area. On the other side, the deployment cost (D) is assumed to be linear, i.e. it increases with the area. If we assume (δ) is the increasing constant of the deployment, then, $D = \delta \times A$. Finally, CAPEX and OPEX (CO) factors as a function of area can be expressed as:

$$CO(A) = Rnt + M + D = (\theta \times A) + (\epsilon \times A \times M_p) + (\delta \times A) \quad (5)$$

5) Environment: in a trial made in 2007, combined wind and solar systems were used to power a base station for a period of three years, which saved roughly 4,580 kg of CO2 each year compared to grid electricity [24]. We can conclude that CO2 emission decreases over time on a single site level. Moreover, on system level, increasing the number of green sites yields more CO2 savings. If factor (Env) denotes the CO2 saving, which increases linearly according to time t, starting from an initial value (Env_{int}) that represents the current percentage of CO2 saving. Hence, the model of environment can be given as $Env = Env_{int}e^{\kappa \times t}$, where κ is the saving increasing constant.

With more usage of green technologies, it is possible that such green sources will produce unknown harmful effects. The large amount of used batteries could cause a waste crisis, but thanks to recycling, each part of the battery can be remanufactured, which is, however, costly. Furthermore, some types of sources have unavoidable hazards, for example, wind turbines can have a deadly impact on birds, biomass energy includes burning trees for cooking and warmth, whilst hydrogen based sources implicate burning the gas, and so on. Hence, the penalty of green sources is denoted as ($Im = -\nabla \times t + Im_{int}$), which is expected to be reduced with time (t), from an initial (Im_{int}), where ∇ denotes the decreasing constant. Accordingly, the total environment cost is given as:

$$En(t) = Env - Im \quad (6)$$

Consequently, the total cost of green source C_g can be given as the combination of all previously mentioned factors:

$$C_g(n, A, t) = S(n) + R(t) + Ec(t) + CO(A) + En(t) \quad (7)$$

V. GREEN CLOUD COST EFFICIENCY

The criteria of measuring the network's CE is superior over bare capacity or spectral efficiency evaluation because CE shows the cost indicator, which gives additional dimension while assessing the network performance. The term CE is used to describe the ratio between spectral efficiency and cost, i.e. (bits/sec/Hz/£). A cloud radio access network architecture is simulated using Matlab software, with M RRHs and U users. The small scale fading between the RRH m and the UE u is $h_{m,u}$, it is assumed to be Rayleigh fading and hence, the power received by the UE u from RRH m is given as $P^{g,r}_{m,u} = P^{g,t}_{rrh}\ h_{m,u}\ r_{m,u}$. Furthermore, $r_{m,u} = d_{m,u}^{-\aleph}$ denotes the path loss between RRH m and UE u and $d_{m,u}$ is the distance between them, $\aleph$ is the path loss exponent, and $P^{g,t}_{rrh}$ denotes RRH transmitted power. Hence, the green CE can be modelled as:

$$CE_G = \frac{B\ log_2(1 + P^{g,r}_{m,u} \Gamma^{g}_{m,u})}{C_g(n, A, t_x)} \tag{8}$$

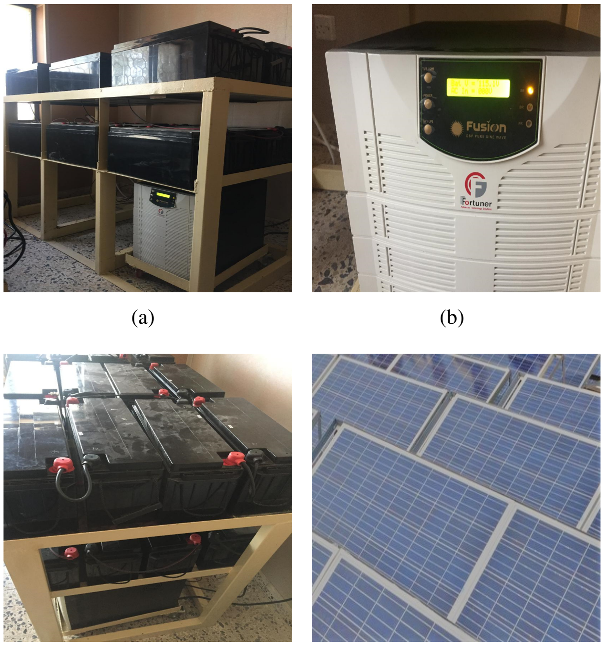
Moreover, the CE of the traditional network is modelled the same way of green CE:

$$CE_T = \frac{B\ log_2(1 + P^{g,r}_{m,u} \Gamma^{g}_{m,u})}{C_T(A, t_x)} \tag{9}$$

Where $\Gamma_{m,u} = \frac{h_{m,u} r_{m,u}}{B\ N_o}$ denotes the signal to noise (SNR) ratio. At a specific time (t_x), where $(0 \geq t_x \leq t)$ the model can give an indication for both green and traditional CEs. It is worth mentioning that $C_g(n, A, t_x)$ is a function of n, A and t_x, while $C_T(A, t_x)$ is a function of only (A) and (t_x) because the traditional grid power is assumed available all the time i.e. $(S(n) = 1)$. Furthermore, $C_T(A, t_x)$ can be evaluated using the same formula of (7), where the value of each factor is differentiated from (7) as shown in Table I.

VI. GREEN SOLAR SYSTEM INSTALLATION

We have installed 60 solar panels of type (Forturner) [25], as shown in Fig. 1. Each panel produces 22KW, which is 50 pence for each 250W and this results in £150/panel. On a sunny day, a panel can produce about 1Amp constantly. These panels charge 24 batteries, each costs £100, with 3 years expiry time. Furthermore, an inverter is installed that costs £200. Hence, the initial cost of this deployment is $(60 \times 150 + (24 \times 100) + 200)$, that is, £11,600. To produce fair results, the time t of (7) is chosen to be 3 years. This period is identical to the expiry battery time. The reason of choosing this time is, after 3 years, the batteries require replacement which imposes extra cost to be added to the model. Hence, the model is required to consider such change in the behaviour of economy metric (Ec), specifically changing the value of Y. It is worth mentioning that the such expiry time is ideal, practically, this time is susceptible to further reduction due to constant use of the batteries. Therefore, the expiry time is decreased by a factor $\wedge$, that is 0.5 year. Hence, the expiry date of the batteries, as a function of time, is modelled as $Act(t) = Ex(t) - \wedge$, where $Act(t)$ denotes the actual expiry date of the batteries, and $Ex(t)$ is the ideal expiry date. In addition, there is no expiry time for the inverter and the solar panel, but rather, they are liable to other equipment fallouts, such as reliability, efficiency and maintenance.



(a) (b)

(c) (d)

Fig. 1: Solar system set up.

VII. RESULTS AND ANALYSIS

All the results have been obtained using Matlab software. Moreover, the most important factor in this modelling is the time t (assumed 2.5 years), as it is responsible of showing when the investors can retrieve their spending, and when the CE of both systems, green and traditional, can be matched. As previously mentioned, over this time, the batteries must be renewed, this means their cost is revived within the total cost.

Factor	Traditional	Green
S	1	0.9902 at n=100
$\aleph$	3	3
R	0.96	0.92
l_c	0.01	0.1
J_{int}	0.2	0.2
I_{int}	0.2	0.2
i_{int}	0.6	0.6
M_{int}	0.5	1
Im_{int}	0.2	0.2
Env_{int}	0.6	0.6
$\wedge$	0.5	0.5
α	0.001	0.009
β	0.001	0.01
σ	0.001	0.015
ι	0.004	0.02
θ	0.0003	0.001
ϵ	0.0002	0.0008
δ	0.0002	0.0006
∇	0.0004	0.0004
κ	0.007	0.007

TABLE I: Model Parameters

The parameters shown in Table I are used to produce the final results of the model. A comparison has been made amongst the two categories, green and traditional. The sufficiency of green source is evaluated using (1), where S is equal to 0.9902, which means the sufficiency is 99.02% at n=100, while the traditional energy sufficiency is equal to 100% and downscaled to 1, which is the maximum value of a the cost for any factor/sub-factor within the model. The economy factor of green case is divided to four pillars, as shown in Fig. 2, whilst the jobs being offered are expected to increase over time from 20% to 50%, similarly to the investment factor, while the ambiguousness is decreased over time. Furthermore, the prices of green devices dramatically decrease with time. Because the model gives futuristics indications about how each factor rises or falls for each case study, site or country, the final expectation of each parameter can be slightly altered, while keeping the same behaviour. If we assume the traditional case, then the offered jobs are less than green, the opportunity for investment is less than green, and the ambiguousness is less too. Finally, it is worth mentioning that x-axis value i.e. 100, represents 2.5 years of time (t). As such, the value 200 indicates 5 years of time.

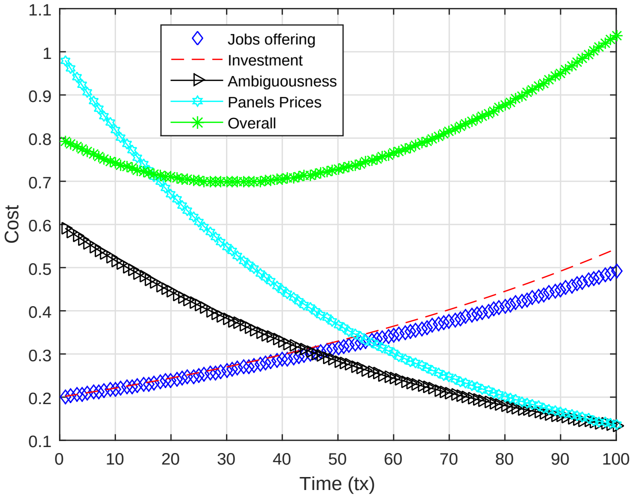


Fig. 2: Economy effect up on the model with respect to time.

Regarding CAPEX and OPEX matrices, usually, the required geographical area for green project is distinctly larger than what is required for traditional generators. In our experiment and according to the solar panels dimensions, the required area is about $550m^2$. However, this area is minimised to about $400m^2$ by tilting and accommodating the panels about 30 degrees toward the sun rise. In addition, the deployment cost D is assumed as being the only installation cost. Since D is linearly proportional to the area, the effect of D factor is higher for green network when compared to the traditional.

The maintenance, rent and deployment costs can be seen in Fig. 3, with all increasing with the area. The environment factor can play crucial factor in deciding which technology is to be adapted to power the network. Regarding the green form, it is very demanding to reduce the harmful emissions, including CO2. Hence, it was assumed that the influence of environment cost is much less compared to traditional generators. Specifically, the assumption was made that the green energy would reduce the CO2 emissions cost from 0.6 to 0.3 in 2.5 years, as shown in Fig. 4, while traditional source would up-scale the cost from 0.6 to 1.

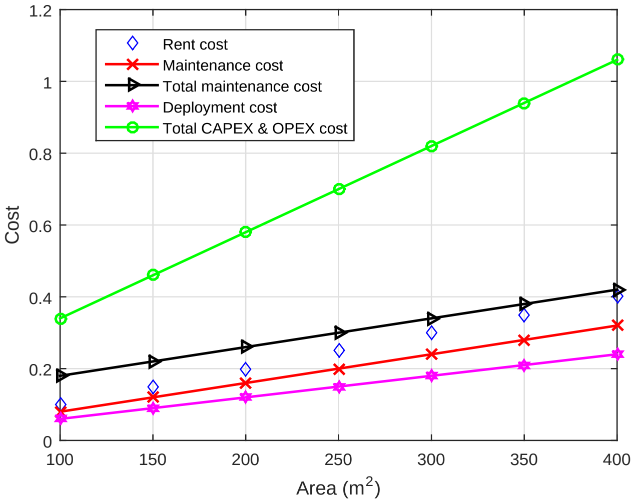


Fig. 3: Maintenance, rent and deployment effects up on the model with respect to the area.

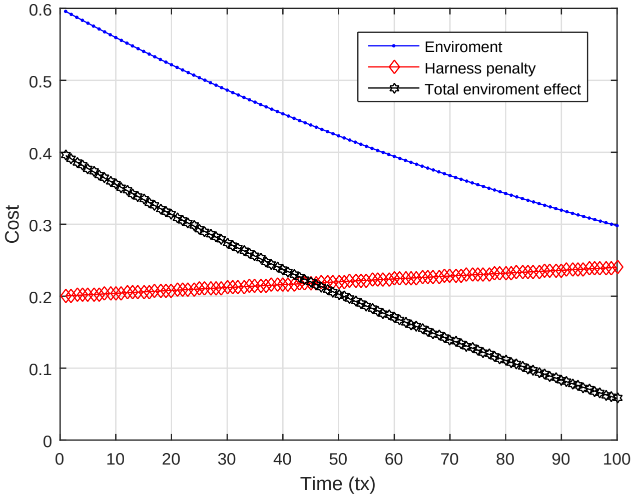


Fig. 4: Environment effect up uo the model with respect to time.

Fig. 5 shows the total cost comparison of green and traditional sources, where it can be seen that the initial investment of green sources is almost doubled in comparison to traditional. As we have assumed the spending of this experiment (£11,600) is equivalent to 1 in the cost pattern. Hence, multiplying the costs of Fig. 5 by £11,600 yields the total cost of the two competitors. Accordingly, the data of Fig. 6 can be easily converted to an indication of CE (SE/£). Hence, it is very necessary to consider this enlarged amount of expenses if shifting from traditional to green. Nevertheless, the costs of green and traditional sources equalise after 40% of time, i.e. at 1 year. Thereafter, it is possible to recover the green expenses quickly as the total green cost drops dramatically.

By using (8), it is possible to obtain the CE performance, as shown in Fig. 6, where it is clear that the traditional method

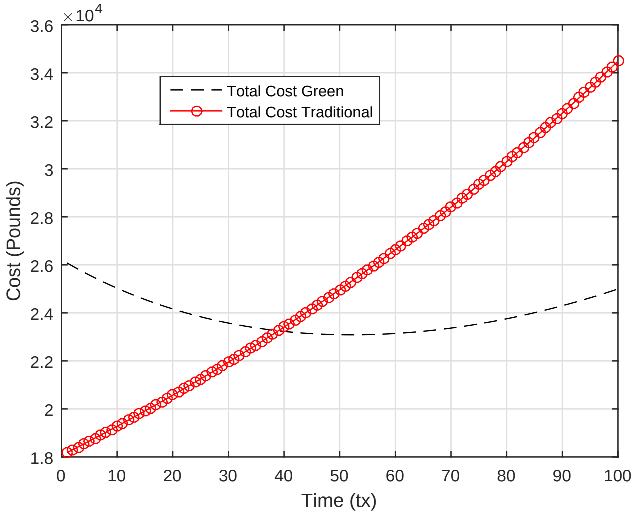


Fig. 5: Total cost comparison of green and traditional sources.

performs better most of the time. That is, the CE of traditional method is initially double the green one, because of the high primary investment, set up and expenses of that technology. After 70% of the set time period, the green cost ($C_g(n, A, t_x)$) becomes less, which leads the green CE moving ahead of its traditional counterpart. The price for batteries represents 25% of the total cost of this experiment and hence, after 2.5 years, the green CE drops by this amount as these batteries are subjected to a replacement.

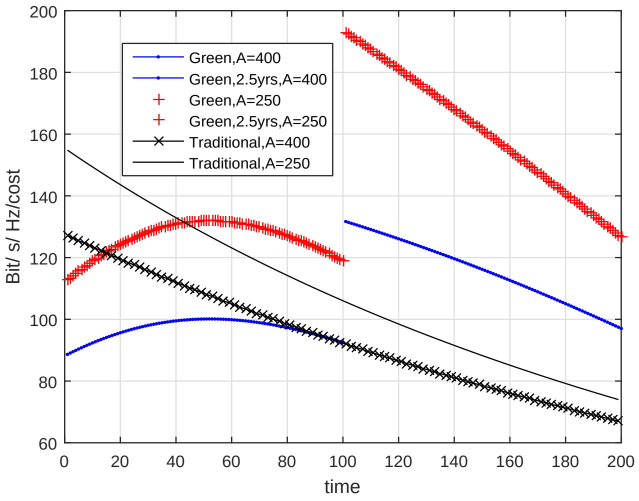


Fig. 6: CE performance for traditional and green methods for 5 years.

VIII. Conclusion and Future Aspects

This paper has presented a model that shows the trade-offs involved with green and traditional energy sources. The proposed mathematical model helps in understanding the different variables that indicate when green sources are favoured over traditional ones. Despite the model being specific regarding the number of solar panels or batteries deployed, it can serve as a general case to cover different countries, sites, equipment prices and specifications. For example, the current prices of panels vary for different countries, as these are affected by tax rates, import costs, manufacturing costs as well as type of panels and batteries, amongst other things. Based on the experimental data, this research has shown that the initial cost of green energy is twice that for the traditional forms. However, this cost can be retrieved in about one year, followed by a large CE gain. However, after 2.5 years, the cost of battery replacement degrades the CE, which results in the two forms of energy sources having equivalent CEs. The CE of different renewable energy sources can be compared to our proposed model to promote green-green comparisons, for example, comparing solar panels with wind turbines while considering a specific geographical area. In addition, this work opens up a discussion about any performance metric that influences the green network in the long term, such as environment or economy. As such, the proposed model can be used as a tool to assess the CE of the different 5G technologies and proposals while powering them using green energy in comparison to traditional, for example studying green software defined networks, fog radio access networks, internet of things and radio over fibre.

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