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5G Mobile Challenges: A Feasibility Study on Achieving Carbon Neutrality

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Abstract— **Increasingly mobile data traffic and high quality service demand has driven fast standards development and new mobile technologies deployment. Traffic demand in 5G networks is expected to rise unprecedentedly, bringing mobile network operators (MNOs) additional challenges, and added pressure regarding carbon footprint reduction. This work aims to study the environmental and financial feasibility of MNOs becoming carbon neutral, by developing biotic carbon dioxide sequestration programs. If feasibility exists, it would be extended and applied to future networks and other environmental scenarios. It is shown that achieving carbon neutrality is possible for heterogeneous deployments, especially when low energy powered base stations like femtocells exist and that the financial costs of such aim might represent little or negligible additional cost expenditure, with the added value of greener and environmental friendly network operation.**

Keywords* — *5G, carbon footprint, Sustainability, geosequestration, carbon neutrality.

I. INTRODUCTION

Green radio networks is a subject deeply focused upon for several years back. Various studies in the last decade have shown that deploying smaller cell sites improve system capacity [1] with higher impact than other options such as deploying more spectrums, improving media access control (MAC) and modulation methods, or coding improvements [2].

All of the aforementioned factors drove the development of femtocells: low-range, low-cost and low power base stations, enhancing overall system capacity and decreasing overall energy consumption. Femtocells will become commonplace in 5G systems, especially attractive in indoor scenarios, considering that most data transmissions (as high as 70%) occur indoors, where link quality is severely diminished by wall attenuation [3][4]. With 5G mobile networks, services and the usage of smartphones and all kind of connected devices will see unprecedented growth, bringing additional challenges for mobile network operators (MNOs), from several perspectives:

- Higher capacity and throughput demand;
- Resource efficiency maximization, e.g., spectrum;
- Cost effectiveness and reduction;
- Reduction of Energy and Carbon emissions;

Cellular networks' operation generates Carbon Dioxide (CO_2) emissions, contributing to global warming. Most of the observed increase in global average temperatures is a consequence of CO_2 emissions into the atmosphere [5]. This phenomenon is generally known as greenhouse gas effect (GGE). Many different gases contribute to GGE, each having its own impact over the atmosphere, with CO_2 being the one with highest levels of concentration. From 1990 (Kyoto Protocol reference year) to 2014 the world global concentration level of CO_2 in the atmosphere increased from 354 to 396 parts per million (ppm) and global CO_2 emissions increased 61% up to 36 billion tons. Regarding 2015, it was the first time that value was above 400 ppm in average [6]. Environmental impacts caused by GGE are becoming visible and affect world population in different forms, two of the most relevant being climate changes and mean sea level rise, which raises the need for either reducing or compensating CO_2 emissions.

Carbon sequestration (CS) is a term that defines the process of capturing and long-term storage CO_2. It is a form of Geo-Engineering, which aims to reduce the impact of GGE by manipulating environmental processes in order to counteract those effects. Also known as carbon sequestration and storage (CSS, from this point on), it consists of physical, chemical or biological methods of capturing CO_2 from the atmosphere and storing it in another place [7]. The most common CSS methods are geological and ocean storage or biotic sequestration. From 5G networks' perspective as the number of connected users and devices increase exponentially, combined with user behavior regarding data generation, overall power consumption will rise resulting in higher carbon footprints (CF) [8]. Several technologies can contribute to reduce power consumptions on mobile networks and today the telecommunications industry is already addressing CO_2 emissions and trying to become "greener" [9][10].

In this article we study the feasibility of an environmental-aware MNO neutralizing partial or totally its operation-related CO_2 emissions. The applied CSS method is biotic sequestration, with trees used as carbon-based "sinks" through the process of photosynthesis. CF reduction is evaluated for several network deployments and the financial impact of such initiative is quantified and compared to the global cost of the network (capital and operation expenditure – CAPEX, OPEX).

It is beyond the scope of this work to quantify CF and CO_2 offsetting for the end user device and the backhaul network, thus focusing solely on the base stations themselves. The authors are aware that a truly sustainable solution should be considered since birth, and that the proposed methods are only a way of compensating. Additionally, aware exists concerning the usage of technology to compensate CO_2 emissions, when technology itself generates CO_2. It's beyond the scope of this

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work to discuss further than the idea to try to achieve carbon neutrality. Section II addresses briefly CSS techniques and Section III presents the method used to calculate CSS. Section IV details the considered environmental scenario and its CSS capacity. Section V presents the cellular network deployment for which CSS method is applied. Finally, Sections VI and VII present the main results and conclusions, respectively.

II. CSS METHODS

According to Sedjo and Sohngen, CSS is *"the process of capture and long-term storage of atmospheric CO_2"* [10]. In order words, CSS is a process of actively removing CO_2 from the atmosphere and depositing it on certain reservoirs, which can be biological (*e.g.,* trees), geological (*e.g.*, underground rock formations and structures), oceans (*e.g.*, underwater bolsters) and underground sinks such as saline deposits or gas reserves [11]. This is an important technique to compensate (offset) for CO_2 emissions, allowing reducing the effects of global GGE and consequent impacts. This compensation is achieved by taking advantage of natural processes that allow for carbon capturing and transformation thus no longer causing impact over atmospheric processes.

A. Geological CSS

Geological CSS [12] is a method for capturing and trapping CO_2 in appropriate rock formations, mainly underground. The capturing process is done in a gaseous form by using physical and chemical methods and trapping is done by injecting it through a pipeline onto deep geological formations under surface [13]. This process is typically performed on industrial facilities, *e.g.*, steel and cement or power plants.

B. Ocean CSS

Ocean carbon storage is another method, similar to the Geological one, with an expensive capture process associated. The process is very similar whereas in this case, the CO_2 is injected into the oceanic water [14]. It is fundamental to choose the right locations and depth, as there are setbacks that may appear and also risks to environment by using this method.

C. Biotic CSS

Biotic CSS overcomes many of the environmental and cost issues related to geological and oceanic storage. Tree-based CSS does not require technology to perform CO_2 sequestration and does not present any side effects as sequestration is done naturally through photosynthesis [15]- [17]. This is the reason why we focus on this type of CSS in this work. Trees retrieve CO_2 from the atmosphere and store it in several of its parts, including limbs, leaves and roots. This behavior constitutes a GGE mitigation technique, as CO_2 is removed from the atmosphere through photosynthesis and is trapped inside the tree, below and above ground. The higher the photosynthesis the more CO_2 will be sequestrated from the atmosphere and converted into biomass. Carbon storage capacity from trees is limited and increases while trees grow and remains constant after maturity. As the years go by and trees become older, their storage capacity will also diminish. The overall amount of sequestered CO_2 depends on a series of factors including the species of trees, their age, type of soil, climate zones and management [18]. Faster growing species are capable of sequestering CO_2 for higher periods of time. Forests located in temperate regions sequester the least amount of CO_2, when compared to other region's forests [19].

III. BIOTIC CSS MODEL

In this section we present the model used for calculating the amount of CO2 sequestration and storage. As referred, we choose biotic CSS. There are two main methods to calculate CSS: individual tree CSS (ITC) and collective tree CSS (CTC), the latter being a term that this work introduces.

A. Individual Tree CSS

This method focuses on the individual capacity to capture and retain CO2, of a single tree, considering its age, height, diameter, species and location. Chavan and Rasal presented a method for carbon sequestration based on tree volume and wood density and other biophysical measurements [20]. Based on this method but improved by removing complexity of species-related parameters influencing CSS capacity, another method is proposed using average tree figures instead of species parameters by Dubal *et al* [21]. Unwin and Kriedemann presented the principles of CSS using a tree individually and a method to estimate its future sequestration capabilities [22]. The US Department of Agriculture, Forest Service's website provides an individual tree CSS tool, called CUFR Tree Carbon Calculator [23].

B. Collective Tree CSS

The second method for biotic CSS focuses on forests composed by either the same or mixed species. This method considers the same evaluation factors as the ITC method, further adding factors like tree spacing and density over a certain area. This is the CSS calculation model that this work focuses on with CO_2 offset analysis being supported by the official UK's Forestry Commission Woodland Carbon Code initiative [24]. From it, datasets and computer models called Carbon Lookup Tables were created to help develop CSS programs. Estimates of CO_2 sequestration were produced for stands of forest trees grown for 200 years from establishment [25].

IV. ENVIRONMENTAL MODEL AND SCENARIO

In this section the considered environmental model and scenario is presented: a typical United Kingdom forest and CTC method, with analysis timeframe divided in to 5-year periods, with the aim of minimizing the yearly variation in growing condition. Thus, this work assumes uniform tree growth per month, yearly [24][25]. Two different categories of trees are considered: broadleaf (BL) and conifer (CON). The former, also known as hardwood, drop leaves when no longer needed, and have higher photosynthesis capacity. The latter - also known as evergreen or softwood - retain leaves all year round, but have less sunlight trapping capacity, as their leaves are mostly needled-type. Regarding tree management, both thinning and free growth (no thinning) are considered. The parameters for CSS calculations are presented on Table I, according to [25]. Other parameters could be used and adjusted to the region, climate conditions and present *florae* in the region of study.

TABLE I. CSS TREE PARAMETERS (EXTRACTED FROM [26]).

Parameter	**Broadleaf (BL)**	**Conifer (CON)**
Species	Beech (BE) *Fagus sylvatica*	Corsican Pine, (CP) *Pinus nigra maritima*
Initial spacing [m]	1,2	1,4
Yeld Class	6	6
Thinned or non-thinned	both	both

A. CTC Life-Cycle Capacity

Using Woodland's Carbon Code lookup tables, cumulative carbon standing (the rate of carbon sequestration for the whole tree, including roots, stem, branch and foliage) per tree type is extracted, either considering 5-yearly thinning operations or free growth [26]. Figure 1 shows the CSS capacity of BL and CON species through a period of 150 years, according to [26] in tons of CO_2 per hectare per 5-year period. BL species have higher CSS capacity over time than CON species.

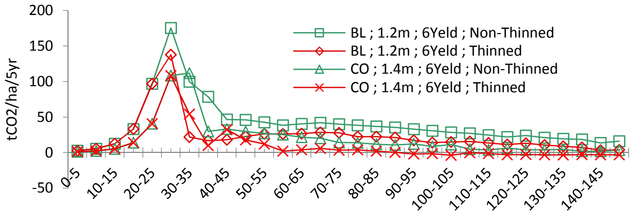

Figure 1– CSS over Time -150 years.

Also, it is shown that thinning process lowers CSS capacity over time. An important aspect is the fact that, independently of the type of tree, the highest CSS capacity occurs while the trees are not yet mature, up to 35-40 years of age. As expected, as trees become older, CSS capacity decreases.

B. CTC Pre-Maturity Capacity

For the purpose of this work, the timeframe for analysis is 35 years. This corresponds to the period when most relevant CSS occurs. Nevertheless, longer periods could be considered with higher CSS capacity gains, which are cumulative.

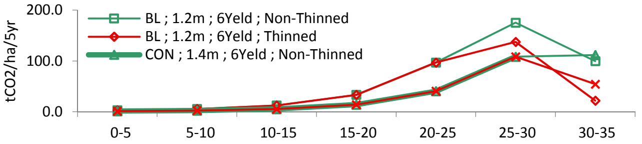

Figure 2 – CSS over Time -35 years.

Figure 2 presents the carbon standing for the reference scenario. It can be seen that in the first 15 years of age, there are negligible CSS differences between both species and also between thinning and free growth. As both species life cycle evolves, CSS capacity increases up to the age of 35. In this case, the considered BL species is capable of sustaining approximately more 35 tons of CO_2 than the considered CON species. Having characterized the environmental scenario, the next section focuses on the costs of neutralizing the cellular activity's CO_2 by means of CSS.

V. CELLULAR NETWORK

A previous work from the authors is considered to evaluate the applicability of the CSS method [27]. One of its main conclusions was that femtocell deployments are cost-effective for high capacity demands, while solving poor indoor coverage, when compared to Macro or mixed Heterogeneous (Femto plus Macro cells) deployments. It was also concluded that femtocells present lower CF, thus most contributing to greener cellular topologies. Based on those topologies, this work evaluates its carbon neutrality feasibility and financial costs, from a CSS perspective, if a MNO decides to embrace such goal. From [27] two scenarios are considered: one with lower traffic requirements, and a second one with 1.5 times more traffic, as summarized in Table II.

TABLE II. CELLULAR NETWORK DATA (EXTRACTED FROM [27]).

Deployment Type	**Scenario Parameters**			
	Capacity ($Mbps/km^2$)	**Carbon Footprint CO_2 ($Ton/yr/km^2$)**	**CAPEX ($M€/km^2$)**	**OPEX ($M€/km^2$)**
Scenario 1 – HetNet < Traffic				
Macro Cell	720	34,2	4,3	0,3
Femto Cell	11960	31,5	0,9	0,4
Joint Split Spectrum	2324	25,8	3,2	0,18
Joint-Common Spectrum	2432	25,8	2,4	0,18
Scenario 2 – HetNet > Traffic				
Macro Cell	6336	300,9	0,5	3,8
Femto Cell	12360	32,5	0,9	0,46
Joint Split Spectrum	7640	216,7	0,35	2,2
Joint-Common Spectrum	7568	162	0,35	1,4

The results show that femtocells present the lowest CF in terms of yearly tons of CO_2 per km^2, in high-density and capacity networks, like Scenario 2. Additionally, heterogeneous (joint) networks present lower CF when compared with macro cell only deployments, with increased capacity. It can also be seen that increasing the capacity requirements in Scenario 2, additional MBS will increase CF significantly (almost 10-fold) while, on the other hand, if a full femtocell deployment is considered, CF will increase only 1 $Ton/yr/km^2$. This means that femtocell only deployments on high capacity requiring scenarios is the solution that minimizes power consumption and thus CF, while maintaining the required network capacity values. Next section will conclude about the feasibility of using CSS methods for achieving CO_2 neutrality for the different deployments.

VI. RESULTS

After defining the environmental and cellular scenarios, the challenge is to apply the CTC Pre Maturity model from Section IV-B, and conclude about compensating CF with the CSS method described, applied to Scenarios 1 and 2. Additionally, it should be possible to conclude about the economical impact for an MNO that decides to embrace such project. Table III presents the CSS capacities per one and five years period:

TABLE III. CSS CAPACITIES (EXTRACTED FROM [25]).

Tree Type	**CSS Capacity (tCO_2/ha)**	
	5 Year Period	**1 Year Period**
BL	180	36
CON	100	25

Scenario 1's worst CF case relates to macrocell only deployment representing 34.2 tCO_2/year/km^2. Table IV presents the results on the relative CSS between Scenarios 1's CF and CSS capacity from the two types of trees. As referred, constant CSS capacity per each one of the 12 months of the year is considered. The results show that BL's CSS capacity is able to surpass all deployments' CF representing for the worst case scenario 5.26% of *"carbon credit"* either when thinning is considered or not. CON species fail to capture and store enough CO_2 for all deployments. For the deployment generating the higher CF, CON CSS capacity represents a 26.9% *"carbon deficit"*.

TABLE IV. RESULTS ON RELATIVE CSS CAPACITY FOR SCENARIO 1.

Relative CSS [%]		**CSS Capacity per tree type (tCO_2/km^2/year)**	
		BL; 1.2m; 6Yeld; Thinned or non-thinned	CON; 1.4m; 6Yeld; Thinned or non-thinned
Scenario 1 – Carbon Footprint (tCO_2/km^2/year)		36	25
Macro	34.2	**5.26 %**	**-26.90 %**
Femto	31.5	**14.29 %**	**-20.63 %**
Joint Split	25.8	**39.53 %**	**-3.10 %**
Joint Common	25.8	**39.53 %**	**-3.10 %**

Results show that if the MNO decides to compensate for its CO_2 emissions, BL species should be the choice, representing positive CSS capacity in all scenarios. In practice, this means that the MNO by choosing BL species CSS will sequester 36 tCO_2/year/km^2 while emitting 34.2 tCO_2/year/km^2, representing a positive "carbon credit" of 1.8 tCO2/year/km^2 in the worst case. Figure 3 shows the different *"carbon credit"* gains for all deployment types.

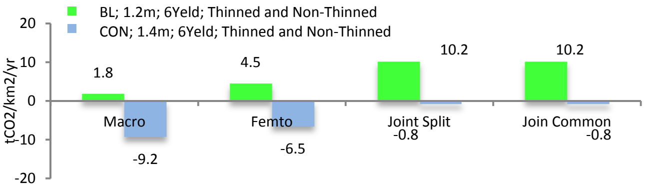

Figure 3 – CSS offset for deployment scenario 1.

The best case is for the joint deployments, but capacity values are below the ones achievable with femtocells. Precisely for this deployment type, the results show that although the femtocell only deployment scenario does not present the lowest CF, there still exist a *"carbon credit"* of 1.8 tCO_2/year/km^2 but with the advantage of being the deployment with the highest capacity value: approximately 16 and 5 times more capacity compared to macrocell only and joint deployments, respectively. As presented in Table I, the CSS capacity considers that each tree is spaced 1.2m per hectare, meaning that a total of 6725 trees would need to be planted generating the presented CSS capacity. We considered a medium cost of 0.076€/tree, which includes terrain price and manual human labor [28]. At that price, 477€ would be the approximate cost for planting all trees, allowing for the MNO to offset positively its environmental footprint. Other prices, hand labor and terrain costs can be considered, as well as terrain made available at no cost by town halls, which are out of scope on this work.

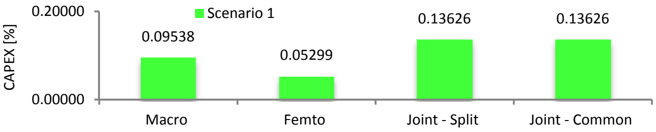

Figure 4 – CAPEX % increase to offset CO_2 emissions of scenario 1.

Figure 4 shows that in the worst case, an MNO would see an increased CAPEX percentage of 0.136%. Focusing on Scenario 2, the most demanding in terms of capacity, it presents worst CF standing at 300.9 tCO_2/year/km^2. CSS capacity is 324 and 225 tCO_2/year/km^2 for BL and CON species, respectively. Table V presents the results. It can be seen that in this case, for the capacity requirements, the CF for femtocell deployment is only 1 tCO_2/year/km^2. Contrasting with the results for Scenario 1, it can be seen that CON CSS capacity is now able to present *"carbon credit"* in three deployment types and *"carbon deficit" is* only present in the worst deployment type, where CSS capacity s 25,2% below the requirements.

TABLE V. RESULTS ON RELATIVE CSS CAPACITY FOR SCENARIO 2.

Relative CSS [%]		**CSS Capacity per tree type (tCO_2/km^2/year)**	
		BL; 1.2m; 6Yeld; Thinned or non-thinned	CON; 1.4m; 6Yeld; Thinned or non-thinned
Scenario 1 – Carbon Footprint (tCO_2/km^2/year)		324	225
Macro	300.9	**7.68 %**	**-25.22 %**
Femto	32.5	**896.92 %**	**592,31 %**
Joint Split	216,7	**49.52 %**	**3.83 %**
Joint Common	162	**100 %**	**38.89 %**

BL trees once again are able to offset all deployments' CF. The comparison between the "carbon credit" values for both tree types and the several deployment options are show in Figure 5. Once again, this CSS capacity is achieved with BL and CON trees at a spacing of 1.2m and 1.4m per hectare, respectively.

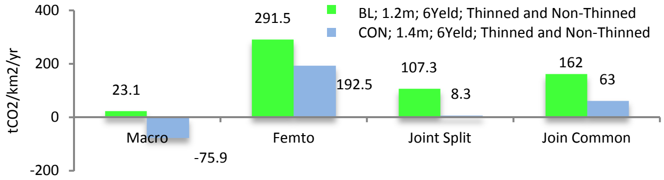

Figure 5 – CSS offset for deployment scenario 2.

To achieve such CSS capacity 56475 trees would have to be planted. Considering the same cost per tree, a total of 4292€ would be needed for an MNO to minimize its environmental footprint. The CAPEX would increase by 1.08% in the worst case, but in the best case from network capacity standpoint, only 0.42%. In this case, the lowest CAPEX rise corresponds to the highest cellular capacity deployment (Figure 6). As expected, the results show that offsetting CO_2 emissions can be accomplished with small amounts of CAPEX increase (with terrain and labor cost considered in the cost per tree, as stated before).

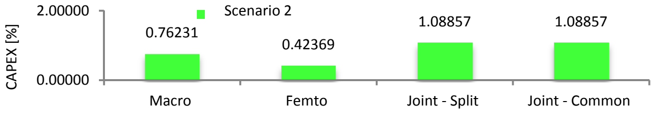

Figure 6 – CAPEX % increase to offset CO_2 emissions of scenario 2.

Complete CO_2 emission offsetting is possible using biotic CSS, for less than 1,1% of CAPEX increase, in the most demanding case, with higher CF and CO_2 emissions per year.

VII. CONCLUSION

In this work the feasibility of a MNO positively offsetting its CO_2 emissions was evaluated, contributing to a greener environment, by removing CO_2 from the atmosphere. Only network base stations were considered. The feasibility of an *"atomic"* model that would allow for further improvements was evaluated, through the biotic CSS concept and carbon neutrality programs adoption by MNOs. CAPEX and OPEX evaluation was performed to understand the cost implications. In order to evaluate CO_2 offsetting possibilities, different network deployment scenarios were considered and CF derived. For scenarios requiring high capacity levels like the ones expected for 5G networks, we demonstrated that femtocells not only are the most economically viable solution, but also the most environment friendly. While maximizing capacity this becomes a win-win solution for reducing MNO's costs as well as environmental impact. Carbon offset was evaluated through biotic Geo-sequestration techniques using trees, in order to offset CO_2 emissions by plantation, and taking advantage of their natural capacity to capture and storage CO_2 through natural processes. The results show that carbon neutrality can be achieved and carbon emission projects can positively compensate CO_2 emissions into the atmosphere related to daily operations, over existing infrastructures. It was also shown that the required CAPEX is almost negligible, proving that this kind of program should, at least be considered and eventually promoted. Future work will focus on carbon neutrality feasibility for i) other network components (*e.g.*, mobile device) ii) considering different planting terrain costs iii) different radio access technologies, like heterogeneous WLAN + Cellular networks and iii) subscriber behavior from data generation and device usage perspectives.

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