Achieving SCOPE 2 ESG Goals Through Strategic Adoption of Varian's Halcyon linear Accelerator

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Introduction

This study evaluates the achievement of SCOPE 2 goals by a network of cancer hospitals in India through adopting Varian's Halcyon linear accelerator. American Oncology Institute (AOI) is one of the largest cancer care providers networks in South Asia. The group runs 23 linear accelerators and treats around 600 new cancer patients every month in the radiation oncology department. In addition to the core objective of providing quality cancer accessible to people, the group has a keen focus on improving their contributions towards sustainable healthcare practices, social responsibility, and corporate governance as well. This whitepaper analyzes the sustainability benefit achieved through energy savings at AOI Nagpur which is equipped with a TrueBeam STX (C-arm) and a Halcyon linear accelerator (O-gantry).

Scope 2

Scope 2 emissions refer to the indirect greenhouse gas emissions resulting from the generation of purchased electricity from a utility provider. These emissions are a key component of a company's carbon footprint and are essential in the context of Environmental, Social, and Governance (ESG) reporting. The carbon footprint of India's power sector is 0.82 t CO_2/MWh[1].

Siemens Healthineers' (SHS) commitment[2] is to minimize its carbon footprint by reducing Scope 1 & 2 emissions by 90% by 2030 (Scope 3, 28% by 2030 and 90% by 2050). American Oncology Institute contributes to this vision by focusing on reducing Scope 2 emissions by improving energy efficiency.

Linear Accelerator (LINAC)

Linear accelerators are sophisticated machines used in the field of oncology to deliver high-energy X-rays to cancerous tissues. These machines utilize electricity to accelerate electrons and produce radiation that can penetrate the patient body and target tumors with precision. LINACs are crucial in modern cancer treatment, as they provide a safe, non-invasive and effective way to combat the disease. Their ability to adjust the shape, intensity, and direction of the radiation beam makes them invaluable tools in the fight against cancer, offering patients a chance at successful treatment and improved quality of life. Advances in technology have made

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[1] https://cea.nic.in/wp-content/uploads/baseline/2020/07/user_guide_ver14.pdf

[2] https://www.siemens-healthineers.com/company/sustainability

modern linear accelerators even more precise and efficient, improving outcomes and reducing side effects for cancer patients.

As per a report[3] published by CERN in 2022, there are over 10,000 medical LINACs in operation around the world. The report also mentions that less than 10% of patients in lower income countries and 40% of patients in middle income countries have access to advanced radiation therapy through these LINACs. The yield of X-ray beam is low as greater than 99% of the kinetic energy imparted on the electron beam is lost in the form of heat.

These LINACs use electricity for the following functions -

- **Patient treatment** - Electricity is used in generating X-ray beam for treatment.
- **Quality Assurance** - This covers both Machine and treatment plan QA. For Machine QA, electricity is used for checking electrical and mechanical functions of the LINAC. For plan QA, electricity is used for beam generation for checking the plan.
- **Standby Mode** - LINACs are put in standby mode when not in use. This mode has lesser but steady electricity requirements to maintain the critical functionality of the equipment.

Halcyon

The Halcyon linac is a state-of-the-art Linear accelerator from Varian. It's known for its efficiency and patient-centered design, aimed at simplifying and streamlining the treatment delivery process while keeping the clinical outcomes at par with other LINACs. In addition to this, Halcyon also has superior environmental sustainability over the other LINACs available in the market. It won the 2023 Green Innovation Award[4] at the ACES Awards which highlighted its contribution to sustainability in the clinical world.

Following features[5] make Halcyon a unique machine in terms of environmental sustainability and should be explored in detail -

- **Accessibility:** The Halcyon system is designed to be accessible and configurable to meet the needs of various clinics. The Halcyon system uses a dual-layer multi-leaf collimator (MLC), which allows for sophisticated beam shaping and high-quality treatments with minimal radiation leakage. The minimal radiation leakage reduces regulatory requirements for external shielding. Lesser external shielding requirements, along with its smaller footprint reduces the requirements for bunker size and concrete usage[6],[7].

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[3] https://cds.cern.ch/record/2845856/files/document.pdf

[4] 2023 Green Innovation Award

[5] https://varian.widen.net/s/lcmxdvhvfs

[6] https://aerb.gov.in/images/PDF/Radiotheraphy/TYPICAL-6MV-MEDICAL-LINEAR-ACCELERATOR.pdf

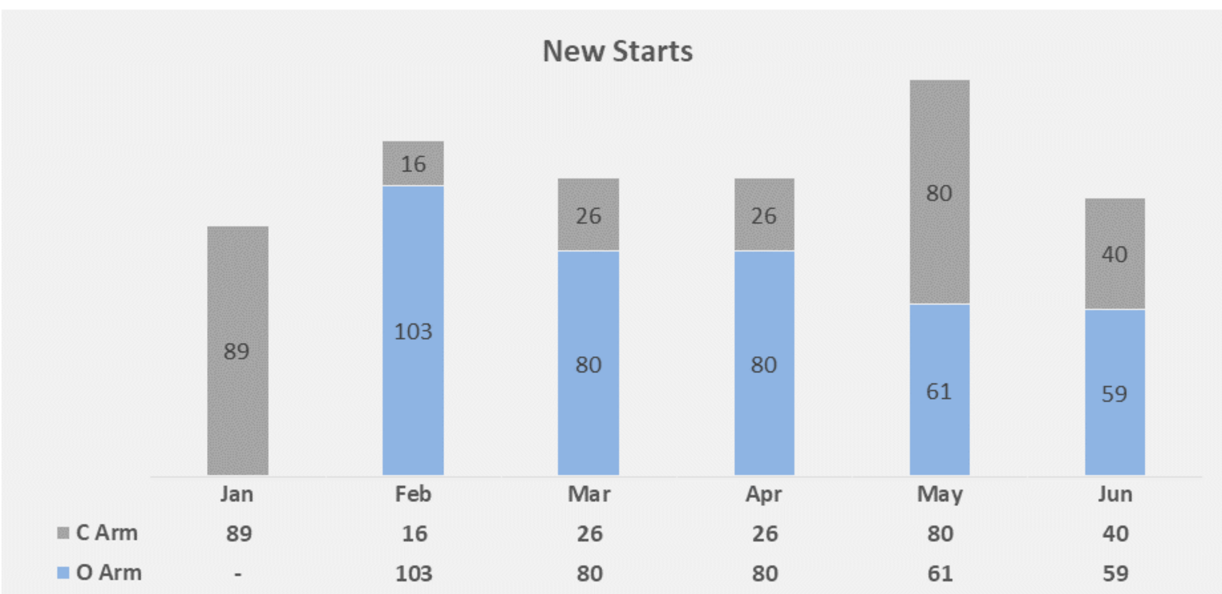
[7] https://aerb.gov.in/images/PDF/Radiotheraphy/TYPICAL-LAYOUT-OF-15MV-MEDICAL-LINEAR-ACCELERATOR.pdf

- **Efficiency:** From installation to treatment, every step is faster and simpler with Halcyon. This means that the time and energy required in installing the machine as well as in treating the patients is lesser than the other LINACs. It's designed to be faster than standard linear accelerators, with the ability to complete cone-beam CT imaging in just 17 seconds[8].
- **Power consumption:** Unlike Dual energy LINAC which has 3 photon (6-15 MV) and 5-6 electron energies, Halcyon has only one unflattened 6 MV photon energy. Lower energy requirements also help cancer centers reduce operational expenses through energy bill savings and provides sustainable advantages as well. This whitepaper further explores sustainability advantages through energy savings from the power consumption aspect at one of the AOI centers.

LINACs at AOI Nagpur

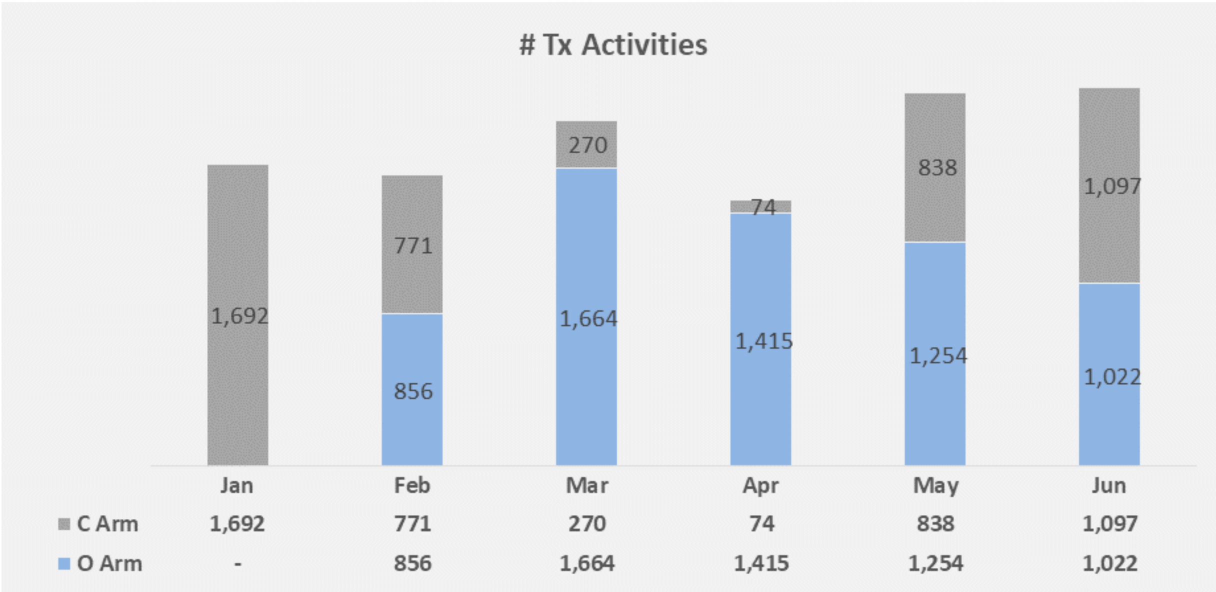
Overview of setup and patient numbers

AOI runs a busy cancer care center in Nagpur, India. This center is now equipped with two LINACs, a C-arm and an O-gantry Halcyon. The dual energy C-arm was commissioned in the year 2018 while the Halcyon was commissioned in Jan 2024. Machine activities and power usage data for the period of Jan - June was analyzed for this article. Over this period, a total of 571 patients-initiated treatment in the unit. On an average 67% patients-initiated treatment on the O-gantry LINAC while 33% initiated treatment on the C-arm LINAC. Following graph depicts the monthly breakup of new starts-



To understand the breakup of activities pertaining to patient treatment, patient fractions, and plan QA activities were combined. Following graph summarizes the number of treatment activities performed on both the machines during this period -

[8] https://varian.widen.net/s/8txlvqmmv8/halcyon_productbrief_operationalexcellence_rad10519a_june2018



Until Halcyon commissioning all patients were treated on C-arm. Patients started on the O-gantry LINAC in the month of Feb, and it became the machine of choice for most patients in March because of similar plan quality with advantage of, faster delivery time and ease of operation. On an average 1826 treatment activities (Patient fractions + Plan QA) were performed monthly on both the machines. While, in the month of Feb around 53% of the total fractions were delivered on the O-gantry LINAC, the figure increased to 67% for the period from Feb to June.

Power consumption activities break-up

As discussed previously in this paper, LINACs consume power under various activities. A detailed analysis of these activities was conducted for both the machines at AOI. Following activities were analyzed -

1. **Patient treatment** - To calculate the patient treatment time, the time difference between first and last fraction was taken from the machine schedule report at the month end.
2. **Quality Assurance (QA)** - Following schedule was followed for QA-
    a. **Daily QA** - Daily both the machines were taken through a structured QA process as per TG 142 protocol. The protocol required an average 30 minutes of time for the QA for each machine.
    b. **Weekly QA** - Weekly both the machines were taken through a structured QA process as per TG 142, TG 151 and TRS 398. The protocol required an average time of 6 hours for the QA for each of the machines.
    c. **Patient specific QA** - Each patient plan underwent a quality check before the start of treatment. The average time taken for each plan QA was 10 minutes.
3. **Standby** - Whenever not in use, the machines were kept in standby mode.

For the activities break-up analysis, Plan QA is clubbed with Patient Treatment activities. Within QA, Daily QA and Weekly QA activities are considered separately. Detailed analysis is provided in the table below -

	Month	# Working days	Total Activities (Fractions + Plan QA)	Daily QA Activities	Weekly QA Activities
C-arm	Jan	26	1,692	22	4
	Feb	25	771	21	4
	Mar	22	270	18	4
	Apr	26	74	22	4
	May	27	838	23	4
	June	25	1,097	21	4
O-gantry	Jan	-	-	-	
	Feb	25	856	21	4
	Mar	22	1,664	18	4
	Apr	26	1,415	22	4
	May	27	1,254	23	4
	June	25	1,022	21	4

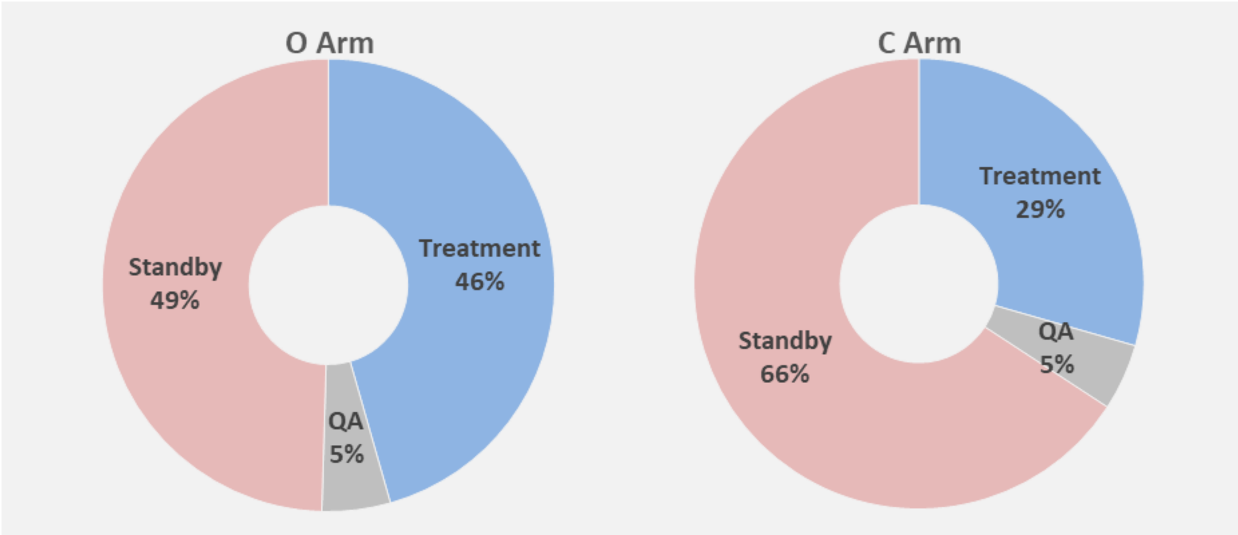
As evidenced in the table, a monthly average of ~1100 and ~1300 treatment activities were conducted on C-arm and O-gantry LINACS respectively. During the same duration a monthly average of ~24 QA (Weekly and daily) activities were performed on each machine.

Activity wise machine time break-up

A time break-up analysis was done on both the LINACs for major activities. Treatment duration included the time each machine was engaged in delivering patient treatment as well as in performing plan QA. Machine QA time included time utilized in both daily and weekly QA. It was assumed that each machine consumes 30 minutes in daily QA and 6 hours in weekly QA. For the remaining time, it was assumed that the machine was kept in Standby mode. While calculating treatment time, it was assumed that each fraction takes 7 minutes on the O-gantry LINAC and 20 minutes on the C-arm LINAC.

	Month	Treatment Duration (Hrs.)	Machine QA (Hrs.)	Stand By Mode (Hrs.)
C-arm	Jan	419	35	291
	Feb	241	35	397
	Mar	89	33	622
	Apr	38	35	647
	May	201	36	508
	June	292	35	394
O-gantry	Jan	-	-	-
	Feb	232	35	430
	Mar	338	33	278
	Apr	367	35	318
	May	352	36	357
	June	321	35	365

It was observed that the C-arm LINAC consumed a monthly average of ~210 hours in treatment activities while O-gantry Linac consumed a monthly average of ~320 hours for the same. Monthly average figure for Machine QA time was 35 hours for each machine. The C-arm machine was on standby mode on an average for ~476 hours each month, while the O-gantry machine was on standby mode for an average of ~350 hours each month. Following pie-chart shows the percentage break-up of the time utilized by each machine on these activities.



Power usage break-up

The unit observed power usage on both the machines during these months which is mentioned in the table below.

	Month	Total Days	# Working days	Total Available Hours	Power Consumed (kWh)
C-arm	Jan	31	26	744	15547
	Feb	28	25	672	13468
	Mar	31	22	744	14423
	Apr	30	26	720	14691
	May	31	27	744	18537
	June	30	25	720	16871
O-gantry	Jan	-	-	-	-
	Feb	29	25	696	5211
	Mar	27	22	648	5918
	Apr	30	26	720	6661

	May	31	27	744	7933
	June	30	25	720	7169

Based on these observations, the C-arm machine consumed an average of ~15600 kWh per month while the O-gantry machine consumed an average of ~6500 kWh per month. This usage was further broken down to understand the power usage on each fraction after excluding power used during standby mode and QA activities.

The power usage in Standby mode was calculated by observing power usage readings at the end of the day to the start of QA activity on the following day. Average hourly power consumption during the standby mode was 15 kWh for the C-arm LINAC and 8 kWh for the O-gantry LINAC.

For calculating hourly power usage during QA activities i.e. daily QA and weekly QA, figures were taken from historic averages of 31.2 kWh and 11.5 kWh for C-arm and O-gantry respectively. Based on these observations, average power consumption for each QA activity was 43 kWh for the C-arm LINAC and 16 kWh for the O-gantry LINAC.

Power consumed during treatment was calculated by subtracting power used on standby mode and during QA activities from the total power consumption. This consumption figure was then divided by the total treatment activities i.e. patient treatment and plan QA to arrive at power consumed during each fraction. On the O-gantry machine, the number of monthly treatment activities varied from 856 to 1664. Average units consumed per fraction varied from 6 - 11.7 kWh for the C-arm LINAC and 1.6 - 3.8 kWh for the O-gantry LINAC. On the C-arm machine the number of monthly treatment activities varied from 74 to 1692. The high variability of power usage per treatment activity on the C-arm LINAC is due to the following factors -

- **Patient numbers variability** - Machine waiting time between the treatment activities reduces with higher number of patients which in turn improves power efficiency.
- **Imaging protocol variability** - CBCT imaging consumes additional power. On O-gantry LINAC, imaging is a mandatory part of the workflow, while on C-arm LINAC, it can be skipped. Physicians and physicists decided the imaging protocol for each patient on the C-arm LINAC.
- **Treatment technique variability** - Every treatment technique requires different Monitor Units (MU) to be fired for each treatment activity. Higher MUs required higher power.

When comparing all 6 months data, the average power usage per treatment activity was 9.3 kWh for the C-arm LINAC and 2.7 kWh for the O-gantry LINAC showing 71% power efficiency for O-gantry. For QA, C-arm LINACs consumed a monthly average of 43 kWh while O-gantry LINACs consumed 16 kWh showing 63% power efficiency for O-gantry. However, since power consumption per treatment activity depends heavily on the total treatment activities for the month, another comparison was done for months with near similar treatment activity numbers. Following two comparable sets were used for this analysis -

- **Set 1 -** Jan for C-arm with 1692 and March for O-gantry with 1664 treatment activities.
- **Set 2 -** June for C-arm with 1097 and June for O-gantry with 1022 treatment activities.

Set 1, with around 1650 treatment activities is representative of a more optimal case load scenario. Set 2, on the other hand with around 1000 treatment activities is representative of a lighter case load scenario which fits initial months of any radiation center. Following table summarizes the power consumption comparison for these sets –

		Tx activities	Power consumption (kWh)/ Tx activities	Power consumption (kWh) QA activities
Set 1	C -Arm (Jan)	1692	6	42
	O-Gantry (Mar)	1664	2	17.3
Set 2	C -Arm (June)	1097	9	43.1
	O -Gantry (June)	1022	3.8	15.9

Both the sets highlight superior power efficiency for the O-gantry LINAC. For treatment activities, power efficiency was 67% and 58% for set 1 and 2 respectively. While for QA activities, the same was 59% and 63% for set 1 and 2 respectively.

Conclusion

This study shows the energy efficiency of the O-gantry LINACs over the C-arm LINACs. O-gantry LINACs save ~4 kWh of power on each fraction delivered. In proportionate terms, this corresponds to saving 58-71% power based on the case load in the unit. This is significant considering the lifetime capacity of the machine to deliver 200,000 fractions running at its optimal capacity which boils down to lifecycle saving of ~860 MWh. Considering the carbon footprint of India's power sector which is 0.82 t CO_2/MWh[9], the total lifecycle ESG savings can be up to ~700 tonnes of CO2 emissions.

This decarbonization is equivalent to saving greenhouse gasses emissions by burning 70,000 gallons of Diesel[10] or CO2 absorbed by 32000 trees[11] in a year. Thus, adoption of O-gantry Linacs is a greener investment which can provide significant opportunity for healthcare organizations to move closer to neutralize their carbon footprint.

In addition to the operational decarbonization benefits discussed in this article, benefits are also attained during installation because of reduced bunker requirements. These benefits can be explored in detail to evaluate the complete impact of strategic adoption of O-gantry linear accelerators. The combination of power

[9] https://cea.nic.in/wp-content/uploads/baseline/2020/07/user_guide_ver14.pdf

[10] https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle

[11] https://www.usda.gov/.

saving, excellent conformal plans, and faster treatment delivery of IGRT plans is a win-win for both patients, health care facilities, and the environment.