Transforming Cancer Treatment in Low-Resource Settings

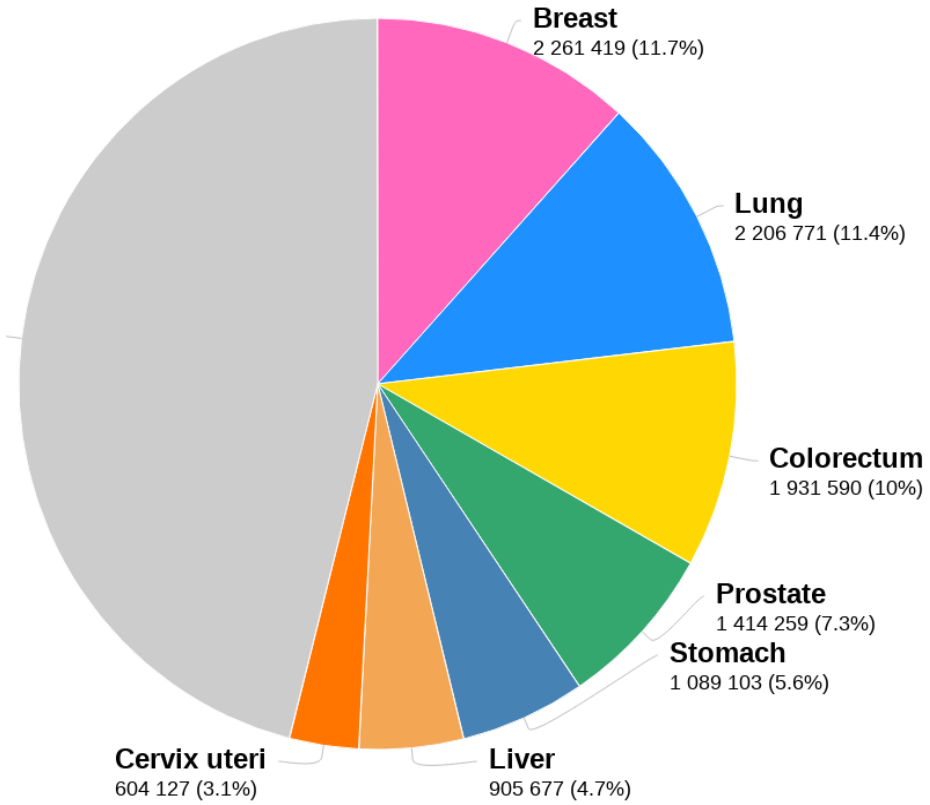
Manjit Dosanjh, ICEC and Oxford, UK
(on behalf of the STELLA collaboration)
26.09.2024

PHYSICS MATTERS @ APS/FIP

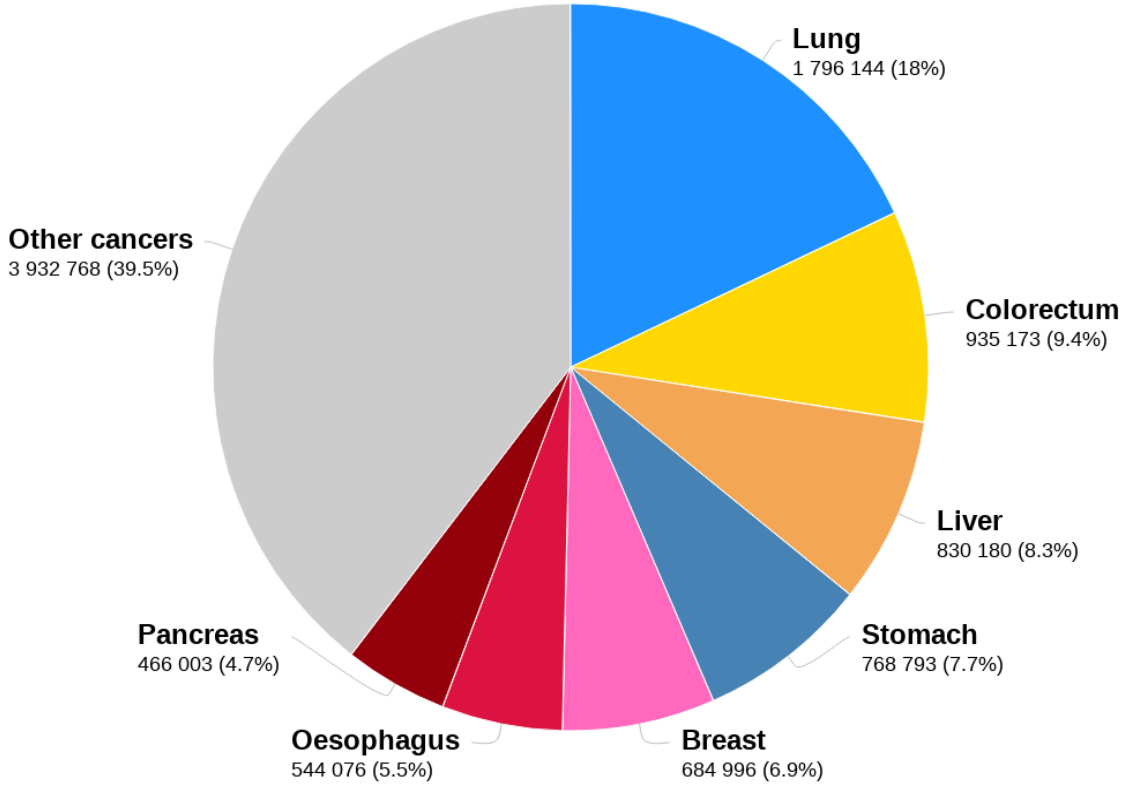
Cancer is a growing global challenge

- In 2022 globally **20** million new cases per year diagnosed and **10** million deaths
- By 2050 this will increase to **35** million new cases per year and 77% increase (lung, breast, colorectal, prostate)
- The impact of this increase will not be felt evenly across countries. Those who have the fewest resources to manage their cancer burdens will bear the brunt of the global cancer burden,"
- Globally about 1 in 5 people develop cancer in their lifetime
- **70% of these deaths** will occur in low-and-middle-income countries (LMICs)
- **9 out of 10 deaths** for cervical cancer and **7 out of 10** breast cancer are in LMICs
- Only 10% of LICs have access to RT

Global cancer incidence and mortality per tumour site (2020)



Total : 19 292 789



Total : 9 958 133

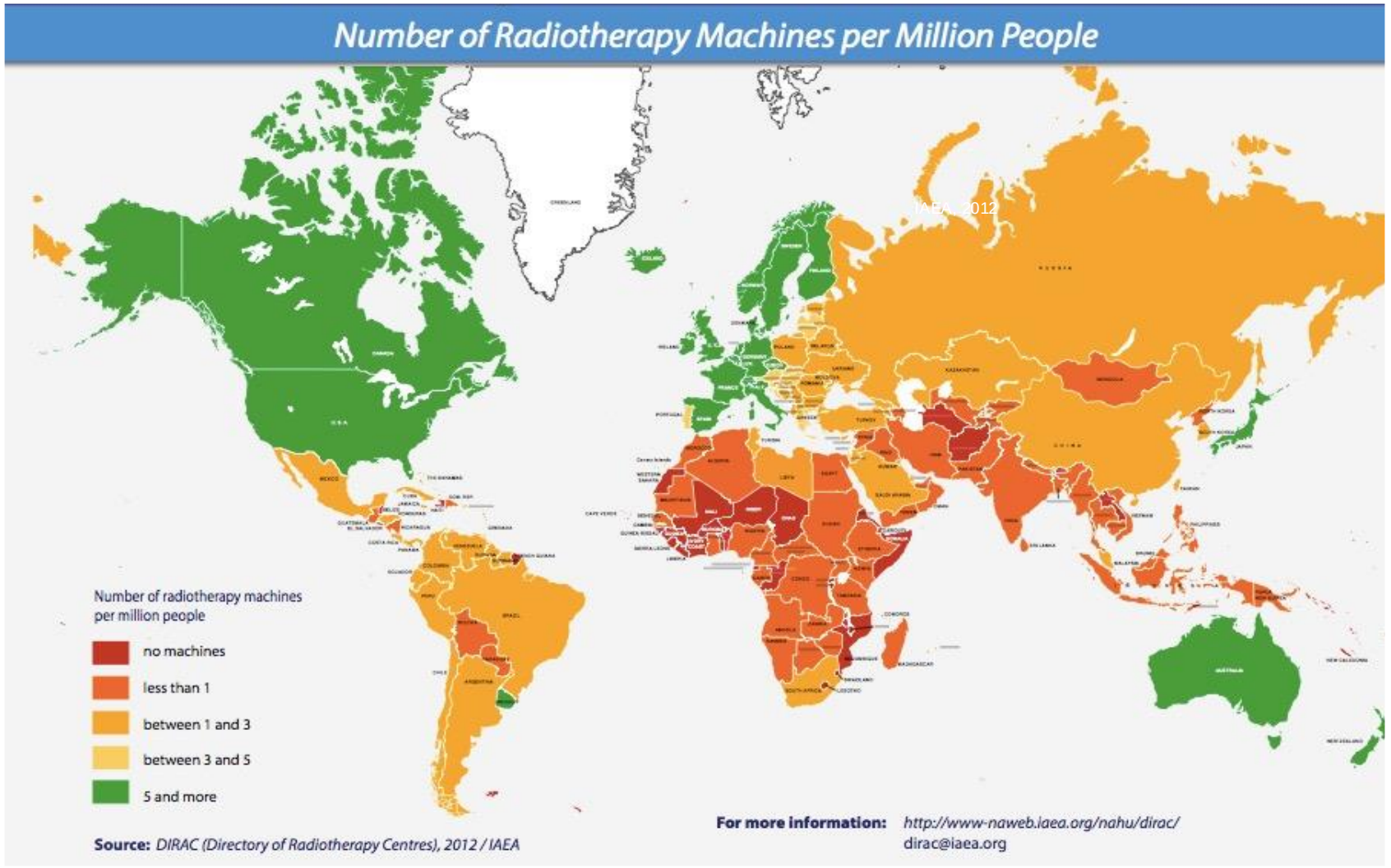
Data source: GLOBOSCAN 2020

The Problem:
Much of the world has limited or no access to Radiation Therapy

1. **Even though RT is one of the most useful tool** for cancer cure or pain-relief there is
   - Inadequate supply of RT linear accelerators (Linacs)
   - Gap greatest in low-middle income countries (LMICs)
   - **Only 10%** patients in Low Income Countries have access to RT
2. **Cannot deliver high-quality cancer care without a well-trained and adequate workforce**
   - Lack oncologists
   - lack of medical physicists, RTTs (radiation technologists) engineers..
3. **If you don't know if you have cancer, you cannot treat it** so imaging technology is key
   - Challenges are similar: lack of imaging devices, lack of experts…..

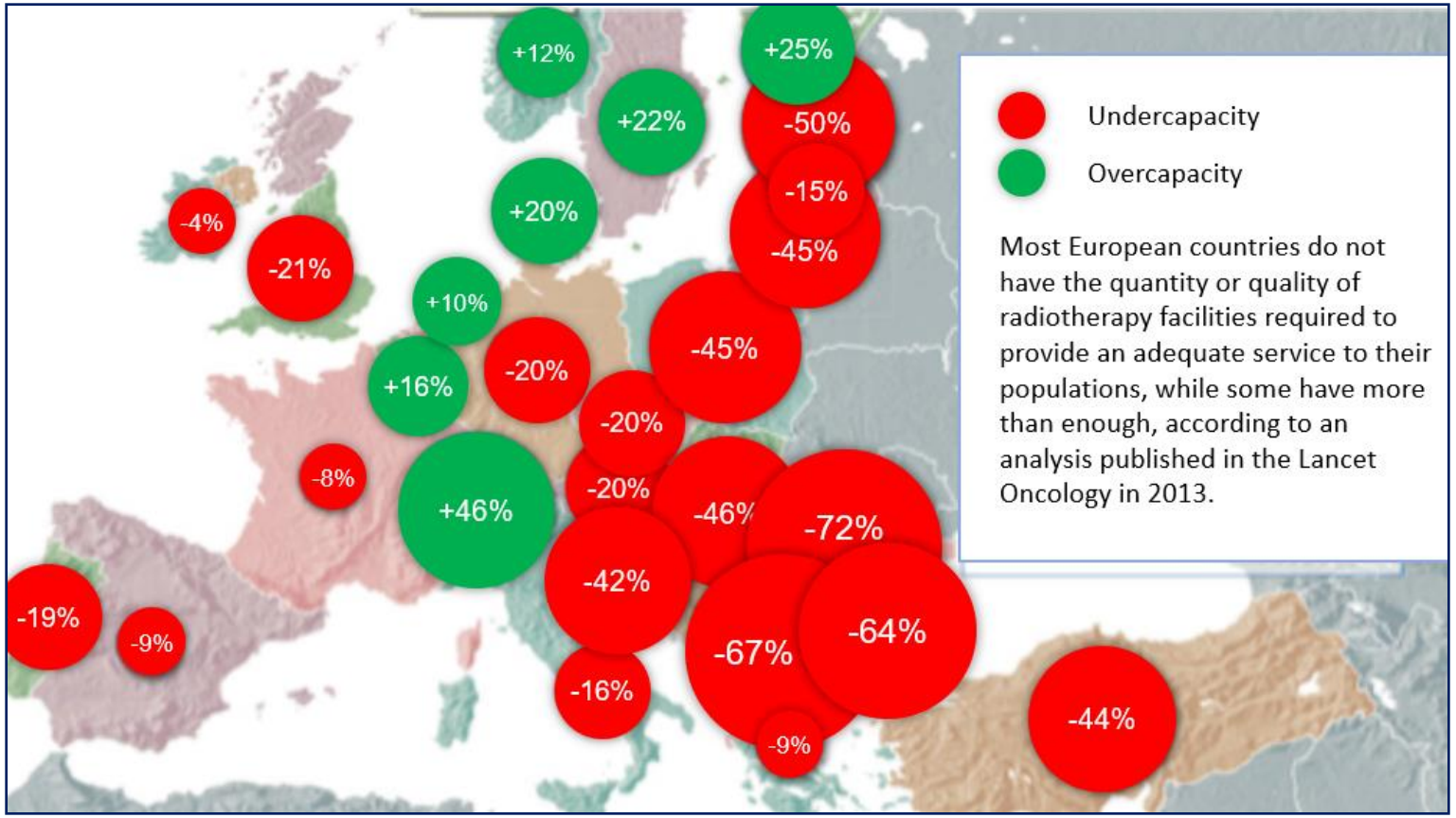
Three key reports highlighted the lack of access to RT

IAEA 2012 data showing huge disparities in global access



Most of the current 18,000 RT units, in 2023, are in HIC (High-Income Countries)

ESTRO Study: Access to RT technology in the European region (2013)



ESTRO – HERO Study (Health Economics and Radiation Oncology): Eastern and South-Eastern European countries need to expand and modernise their radiotherapy equipment.

Global Task Force for Radiotherapy for Cancer Control (GTFRCC) - 2015

The Lancet Oncology Commission

Lancet Oncol, 2015, 16: 1153

Expanding global access to radiotherapy

Rifat Atun, David A Jaffray, Michael B Barton, Freddie Bray, Michael Baumann, Bhadrasain Vikram, Timothy P Hanna, Felicia M Knaul, Yolande Lievens, Tracey Y M Lui, Michael Milosevic, Brian O'Sullivan, Danielle L Rodin, Eduardo Rosenblatt, Jacob Van Dyk, Mei Ling Yap, Eduardo Zubizarreta, Mary Gospodarowicz

Our results provide compelling evidence that investment in radiotherapy nc only enables treatment of large numbers of cancer cases to save lives, but also brings positive economic benefits.

The verdict is in: the time for effective solutions to the global cancer burden is now *C Norman Coleman, Bruce D Minsky

Lancet Oncol, 2015, 16: 1146

GTFRCC: "Our results provide compelling evidence that investment in radiotherapy not only **enables treatment of large numbers of cancer cases to save lives**, but also **brings positive economic benefits**."

2014 was an important year also for STELLA

- it was 60 years of CERN,
- 80th birthday of Ugo Amaldi who gave a public talk on "Physics is not only beautiful but also useful"
- It was the first time that Norman Coleman talked about ICEC (established in 2013) and his vision in the international arena.

ICTR-PHE
2014

World-wide radiotherapy coverage

Status of Radiation Therapy Equipment

156 Countries

7814 RT Centres

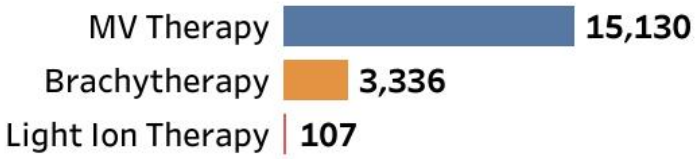
15130 MV Therapy

107 Light Ion Therapy

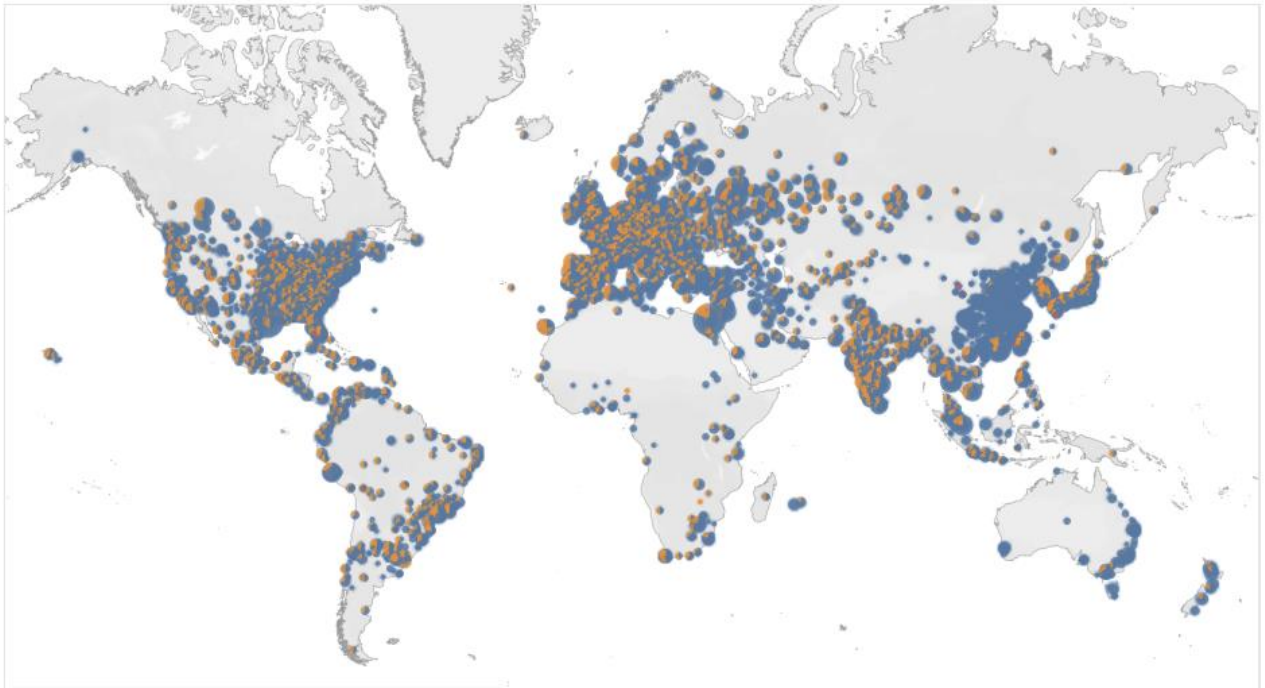
3336 Brachytherapy

Click on **Equipment type**, **Income groups** or **Regions** to create your own view. *Ctrl+click to select multiple items*

Equipment type
(Updated on : 3/9/2023 1:55:27 PM)



Equipment per income groups
(Updated on : 3/9/2023 1:55:27 PM)



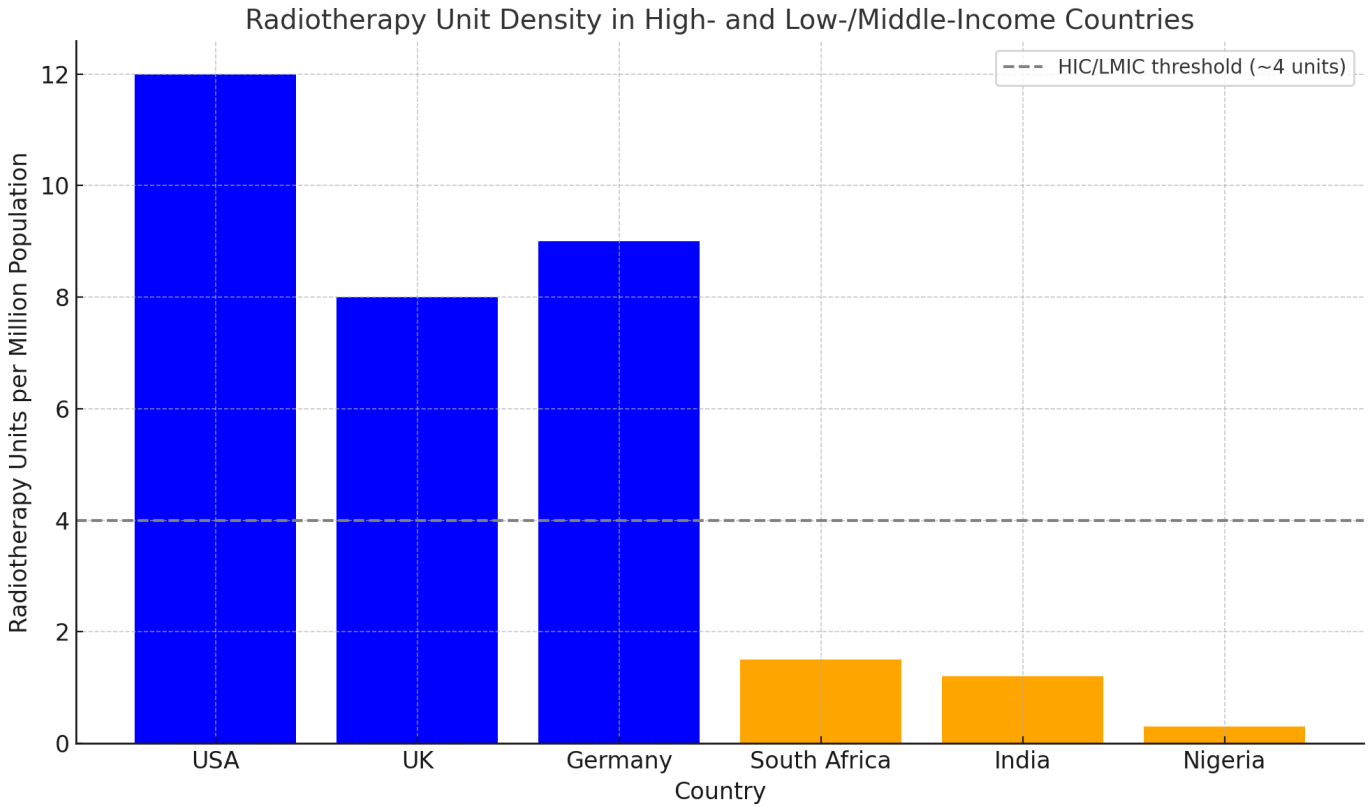
Global Radiotherapy Unit Density per Million Population

- Radiotherapy is critical in cancer treatment, yet many countries face significant gaps in access. According to the WHO, three-quarters of cancer deaths occur in developing countries, where resources are limited.

Data Overview:

•The **global density of radiotherapy units** (including Linear Accelerators and Cobalt-60 units) varies significantly:

- **High-Income Countries (HICs)** often have between **4-12 radiotherapy units per million population**.
- In contrast, **Low- and Middle-Income Countries (LMICs)** have as few as **0.01 to 1 unit per million**(World Health Organization (WHO)).
- IAEA-DIRAC



CT Scanners Distribution per Million Population

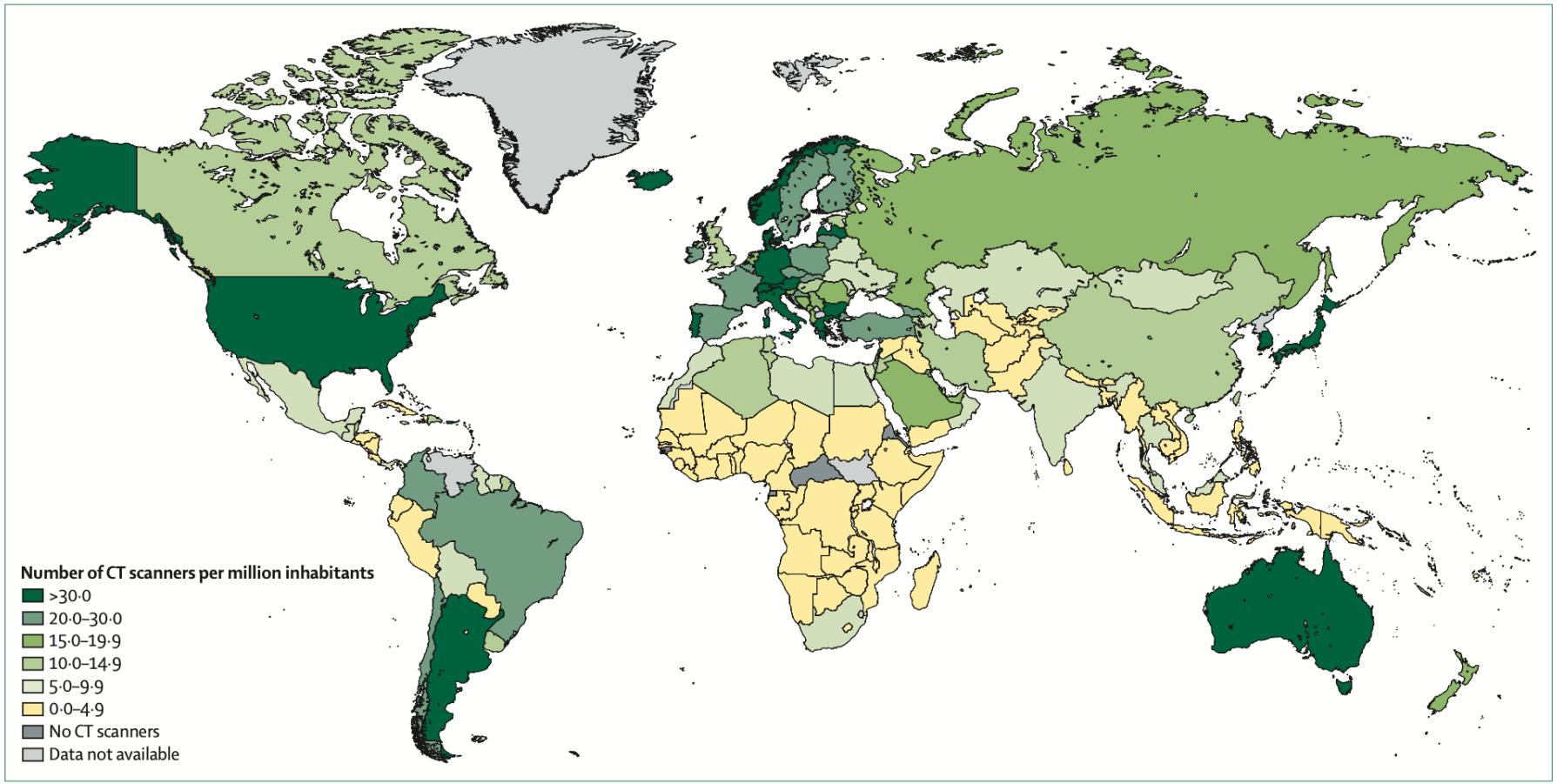
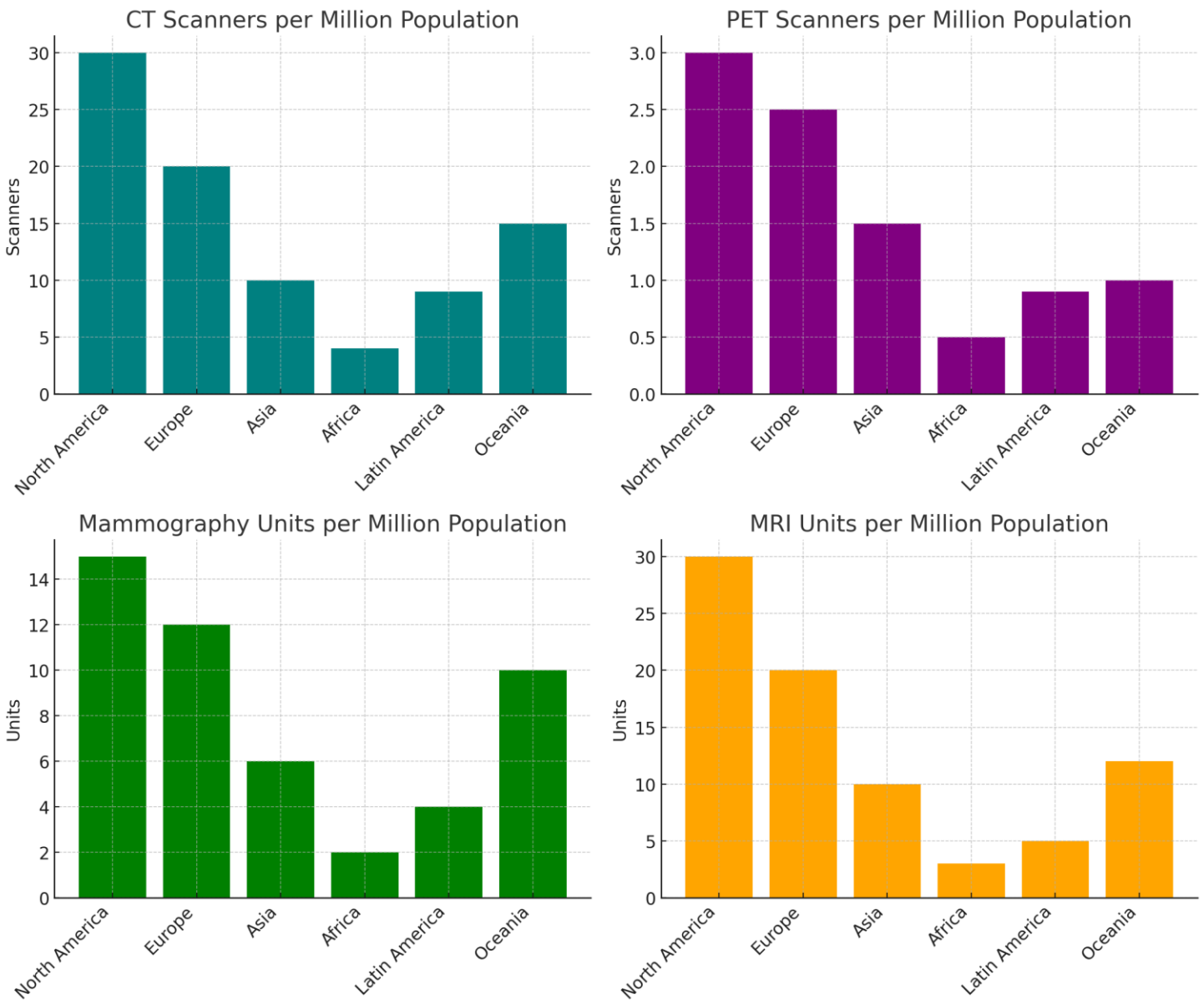


Figure 2: **Estimates of the number of CT scanners per million inhabitants**
Data are from the International Atomic Energy Agency medical imaging and nuclear medicine global resources database (IMAGINE). The map was produced by the International Atomic Energy Agency (Vienna, Austria) and is included here with permission.

CT scanners are an essential diagnostic tool in cancer care. However, high-income regions like North America and Europe have significantly higher access to CT scanners compared to LMICs.

Global Distribution of Medical Imaging Equipment also shows stark disparities

A Comparative Analysis of Imaging Technologies per Million Population



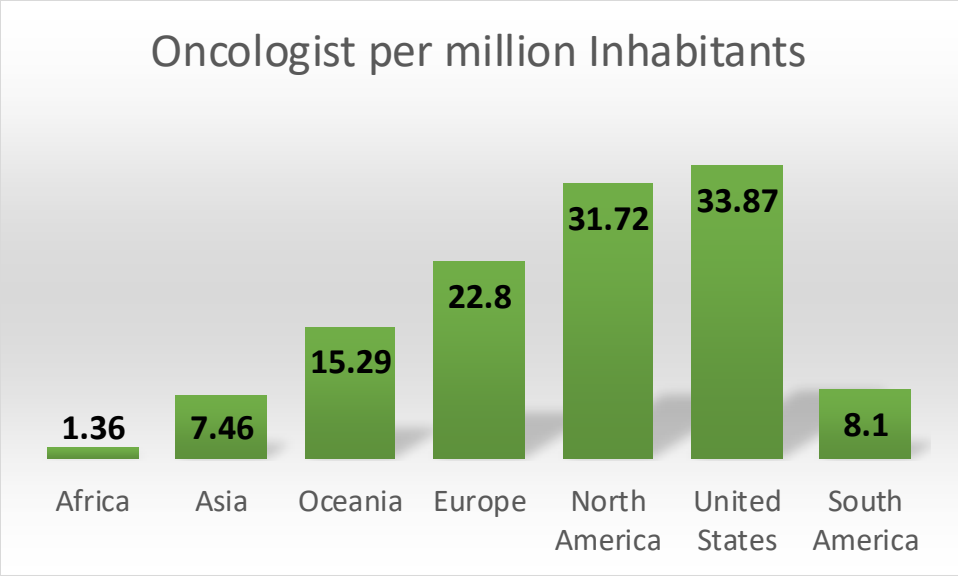
Medical imaging and nuclear medicine: a Lancet Oncology Commission: www.thelancet.com/oncology Vol 22 April 2021

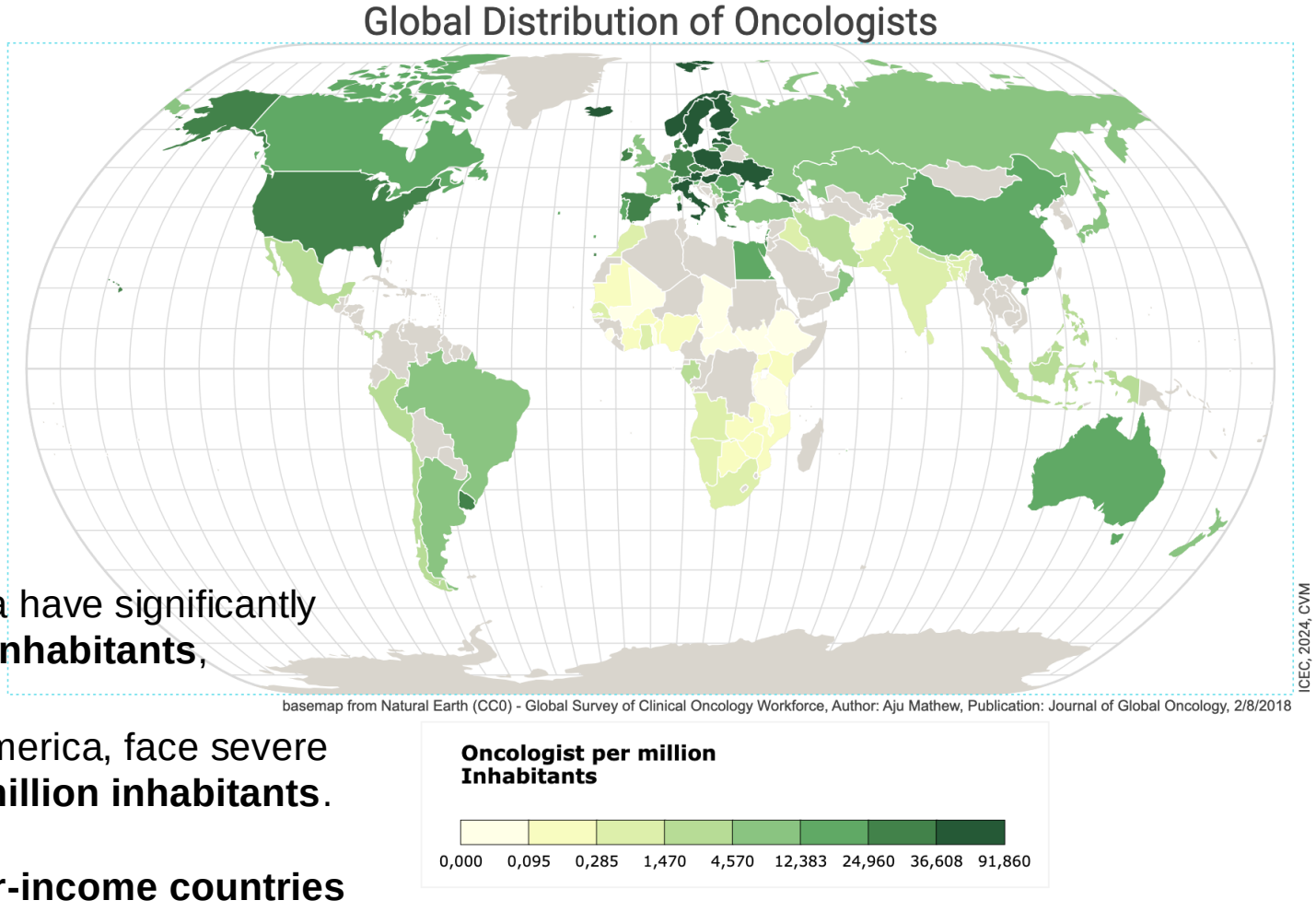
Manjit Dosanjh, Transforming Cancer, 26.09.2024

The global distribution of medical imaging equipment shows stark disparities. There is an urgent need for investment in medical imaging technologies to ensure that patients in all regions have access to life-saving diagnostics.

Disparities in Access to Oncologists

The global distribution of oncologists per million inhabitants varies greatly, highlighting disparities in cancer care.





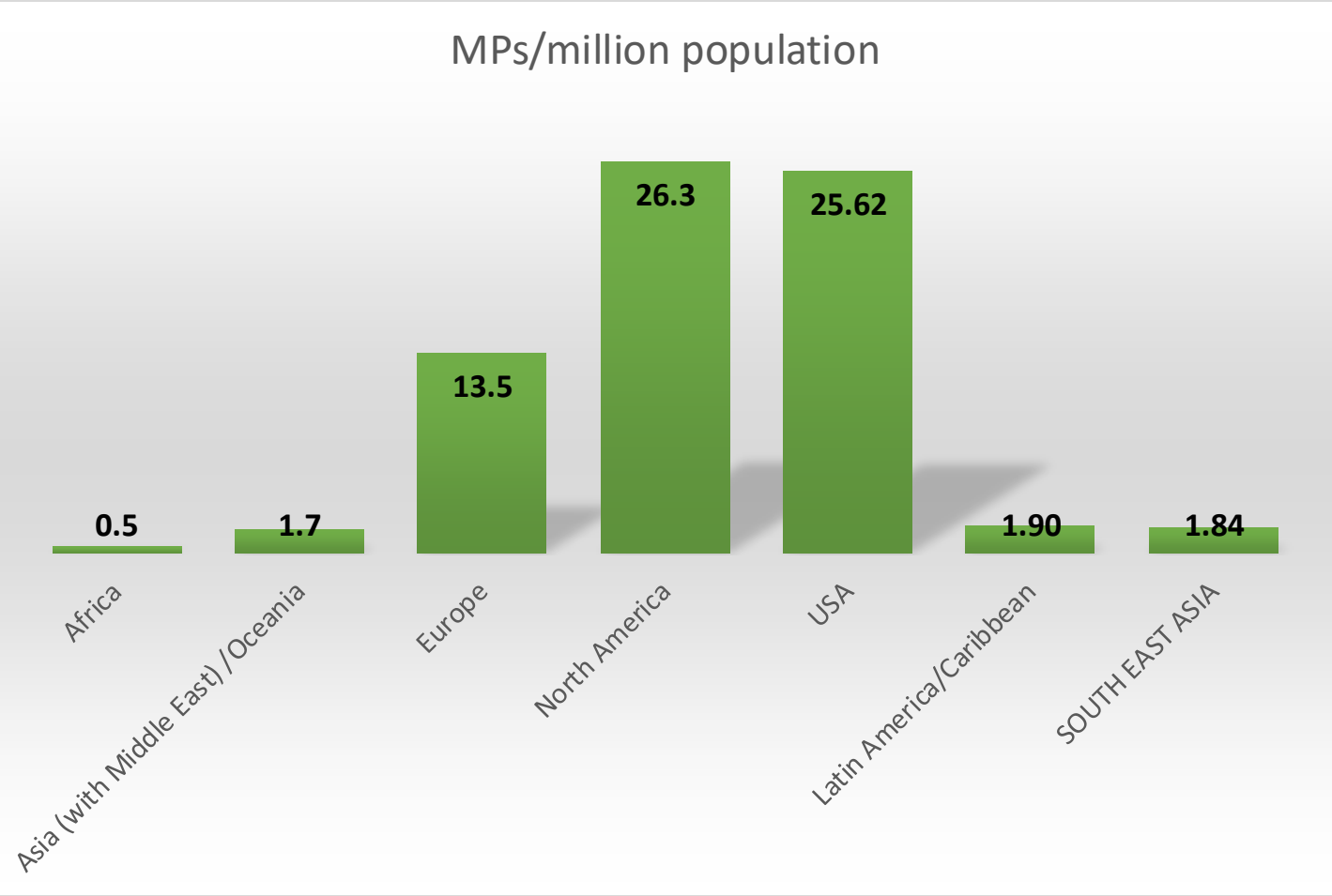
High-income regions like the US and North America have significantly more oncologists, with **33.87 and 31.72 per million inhabitants**, respectively.

Low-resource regions, such as Africa and South America, face severe shortages, with only **1.36 and 8.1 oncologists per million inhabitants**.

This imbalance means that **cancer patients in lower-income countries have far less access to specialized cancer care**, directly affecting outcomes and treatment availability.

Availability of Medical Physicists Worldwide

The distribution of MPs is also uneven, with North America having **26.3 MPs per million**, whereas **Africa lags significantly with only 0.5 MPs per million**.

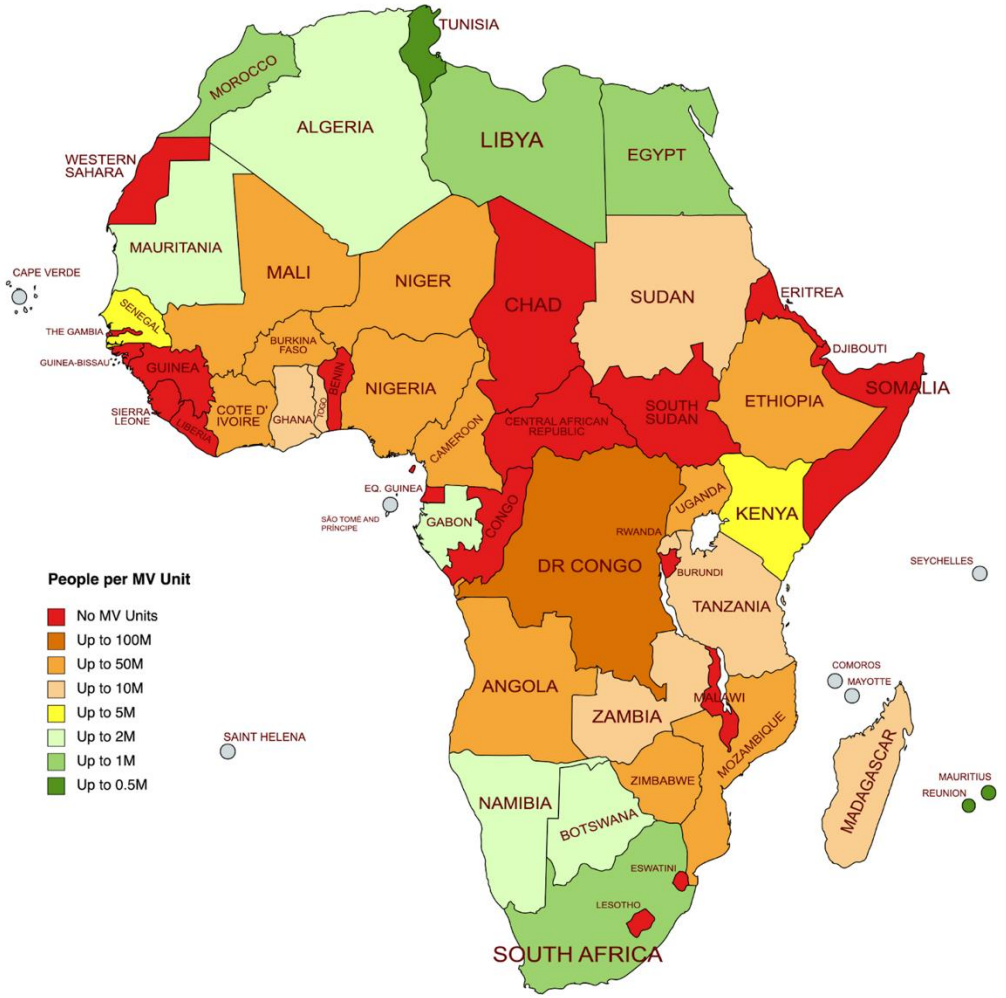


- Europe stands in between with **13.5 MPs per million**, and Southeast Asia has around **1.84 MPs per million**.
- The severe shortage of MPs in regions like Africa and parts of Asia has a profound impact on the quality and safety of radiotherapy services, which are crucial for effective cancer treatment.
- Increasing the workforce of MPs is critical for improving cancer care in these low-resource settings.

Number of people per functioning machine in countries in Africa

But there are dramatic disparities in Access

Africa: 420 MV RT units for around **1.4 billion** people
1 machine per 3.5 million people
US: **3879** MV RT units for around **340 million** people
I machine for 86, 000
UK: **357 MV RT** units for around **68** million people
1 machine per 190,000
Switzerland: 85 for **8.8** million people
1 machine for 100,000

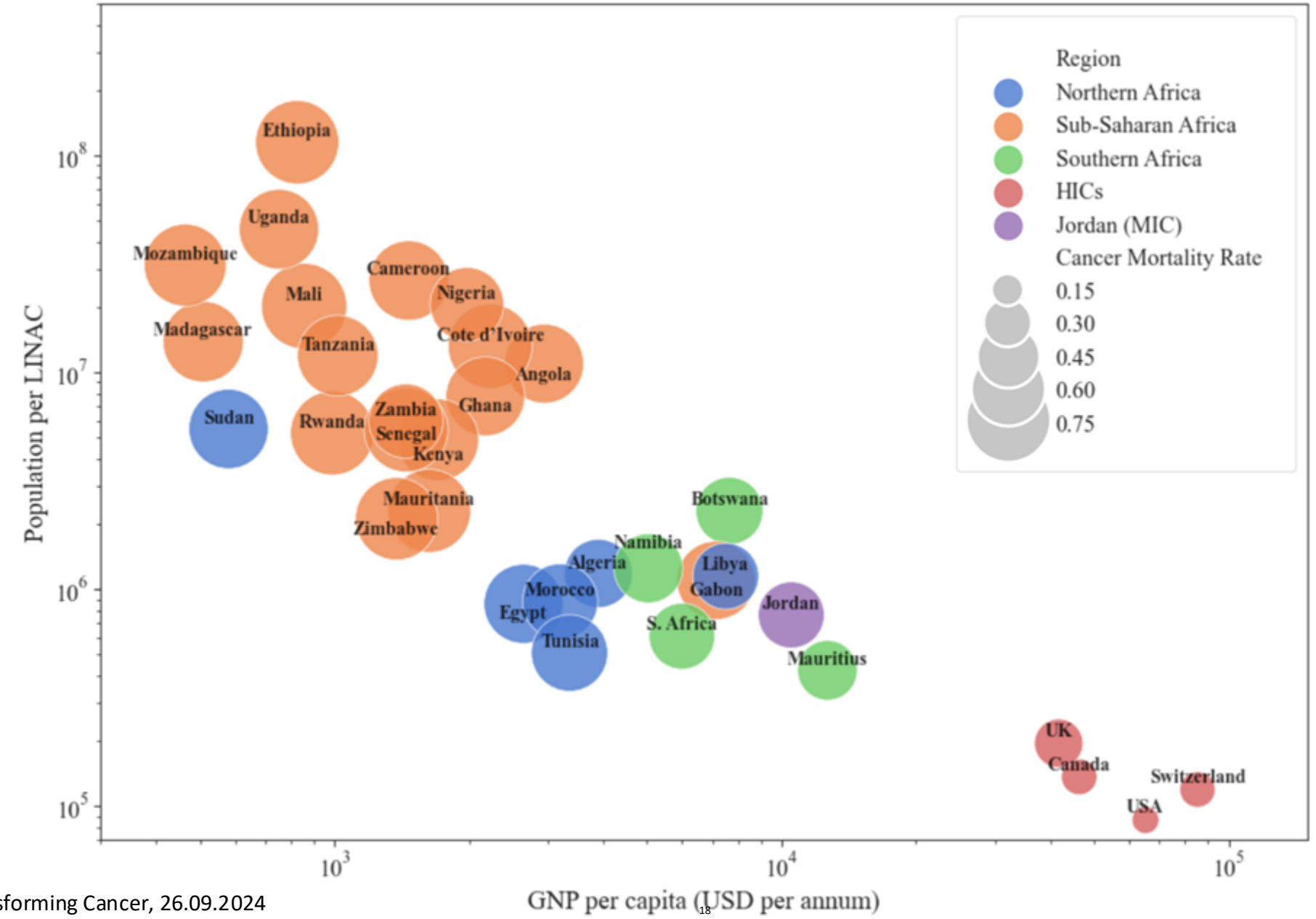


- By 2030, there will be **1.4** million new cases of cancer and there will be **1** million cancer deaths in Africa
- In 2019 only **28** countries had RT facilities
- In 2024 there 34 countries
- Over **60% are in just 3 countries**: South Africa, Egypt and Morocco
- 20 countries have none

AFRICA'S ENVIRONMENT - CHALLENGES

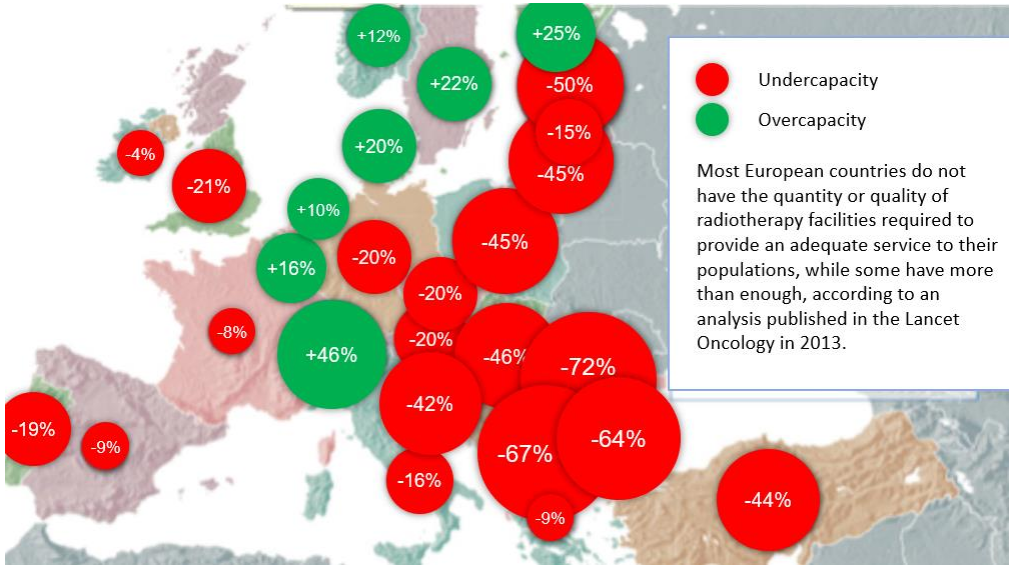
- The lack of infrastructure to ease the accessibility of treatment centres via well-maintained roads and safe and reliable transportation services also poses a huge issue.
- Power outages are quite detrimental and may shorten the lifetime of electrical equipment, eventually resulting in permanent damage.
- Moreover, the lack of certified and qualified personnel to operate and maintain the linacs and associated equipment is one of the biggest problems faced by most LMICs.
- These two last factors have indeed been repeatedly highlighted by professionals in LMICs, indicating the need for local investment in human resources.
- Ranging from the unavailability of accredited programmes to train professionals to the relatively low wages on the job, there is an ongoing brain drain to more attractive countries

GNP and Ratio of Inhabitants to Linacs and Cancer Mortality



Ige et al, *Surveying the Challenges to Improve Linear Accelerator-based Radiation Therapy in Africa: A Unique Collaborative Platform of All 28 African Countries Offering Such Treatment*. Clin Onco, 2021 33e521-e529 https://doi.org/10.1016/j.clon.2021.05.008

Shortages and challenges are not only in Africa



Radiation therapy capacities in Europe 2013

Rosenblatt E, et al. Lancet Oncol 2013;14:e79–86

Manjit Dosanjh, Transforming Cancer, 26.09.2024

SEE (Balkan) Study

Ristova M et al. Cancer patients in the countries of SEE (the Balkans) region and prospective of the Particle Therapy Center – SEEIIST. Advances in Radiation Oncology, 2021, Vol 6. https://doi.org/10.1016/j.adro.2021.100772

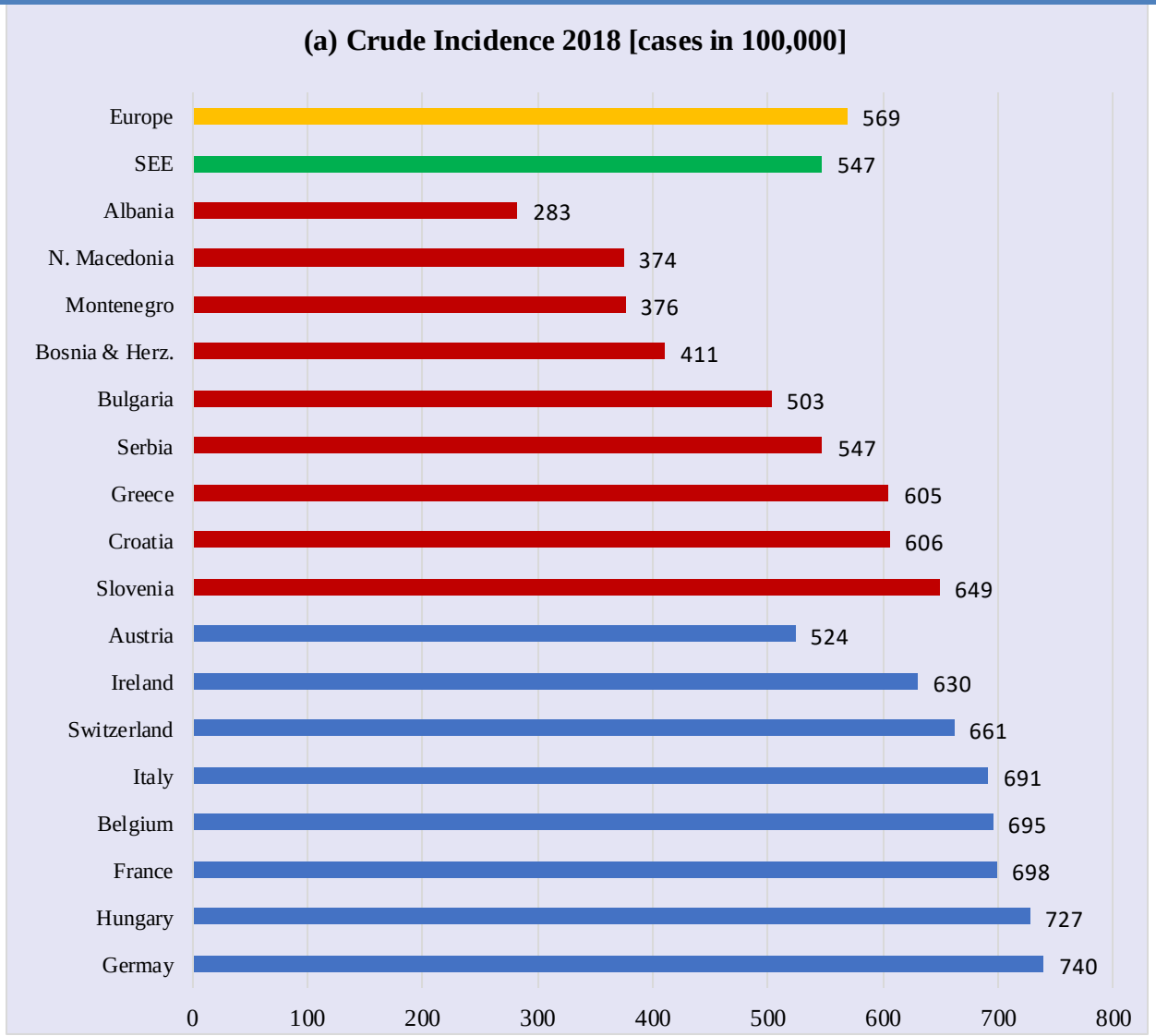
What we know about SEE from the SEEIIST?

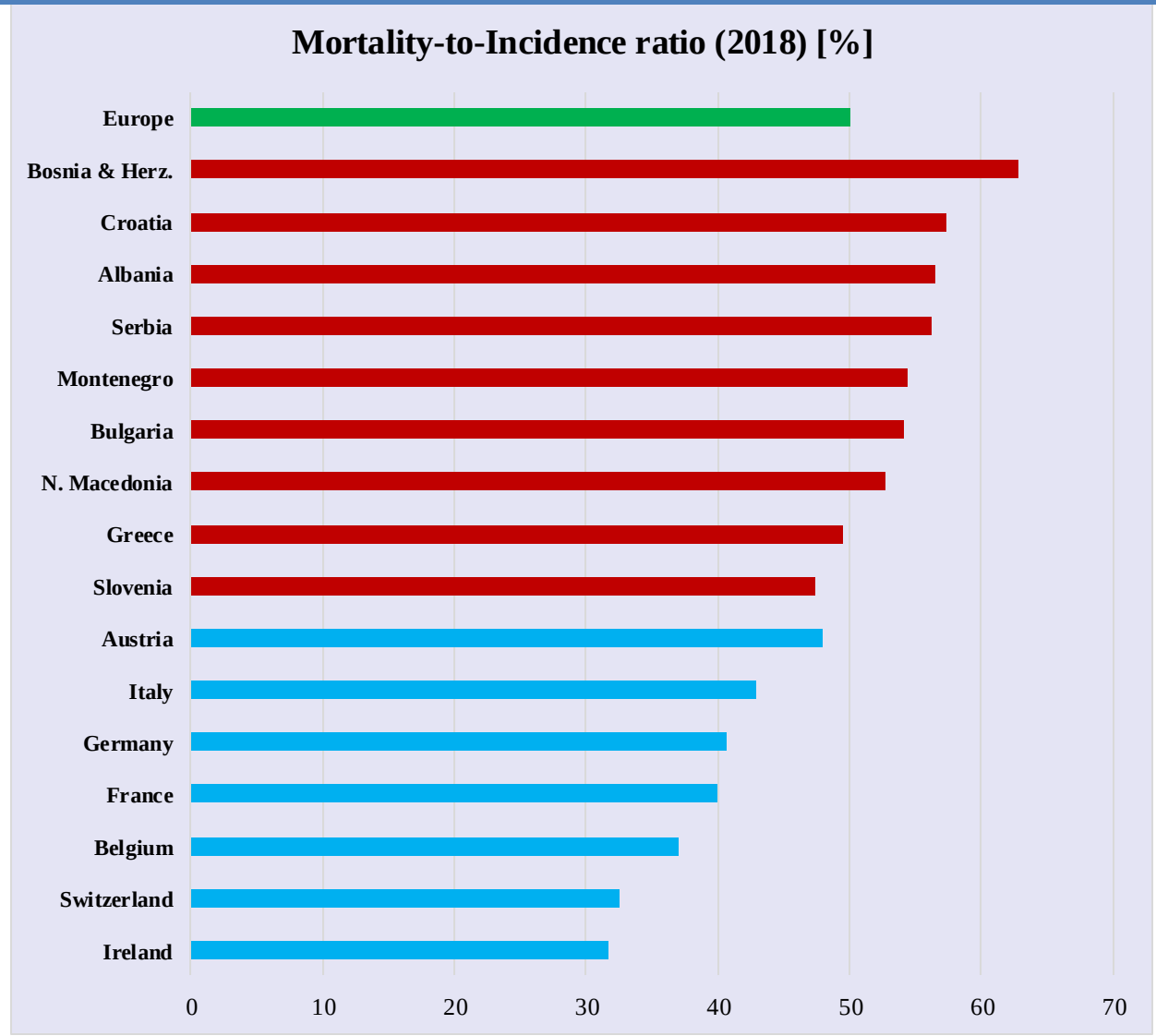
Geographical map of the region

Map of equipment for cancer diagnosis and treatment

Map of human resources and research in particle physics

Cancer Incidence and Mortality-to-Incidence ratio (MIT)

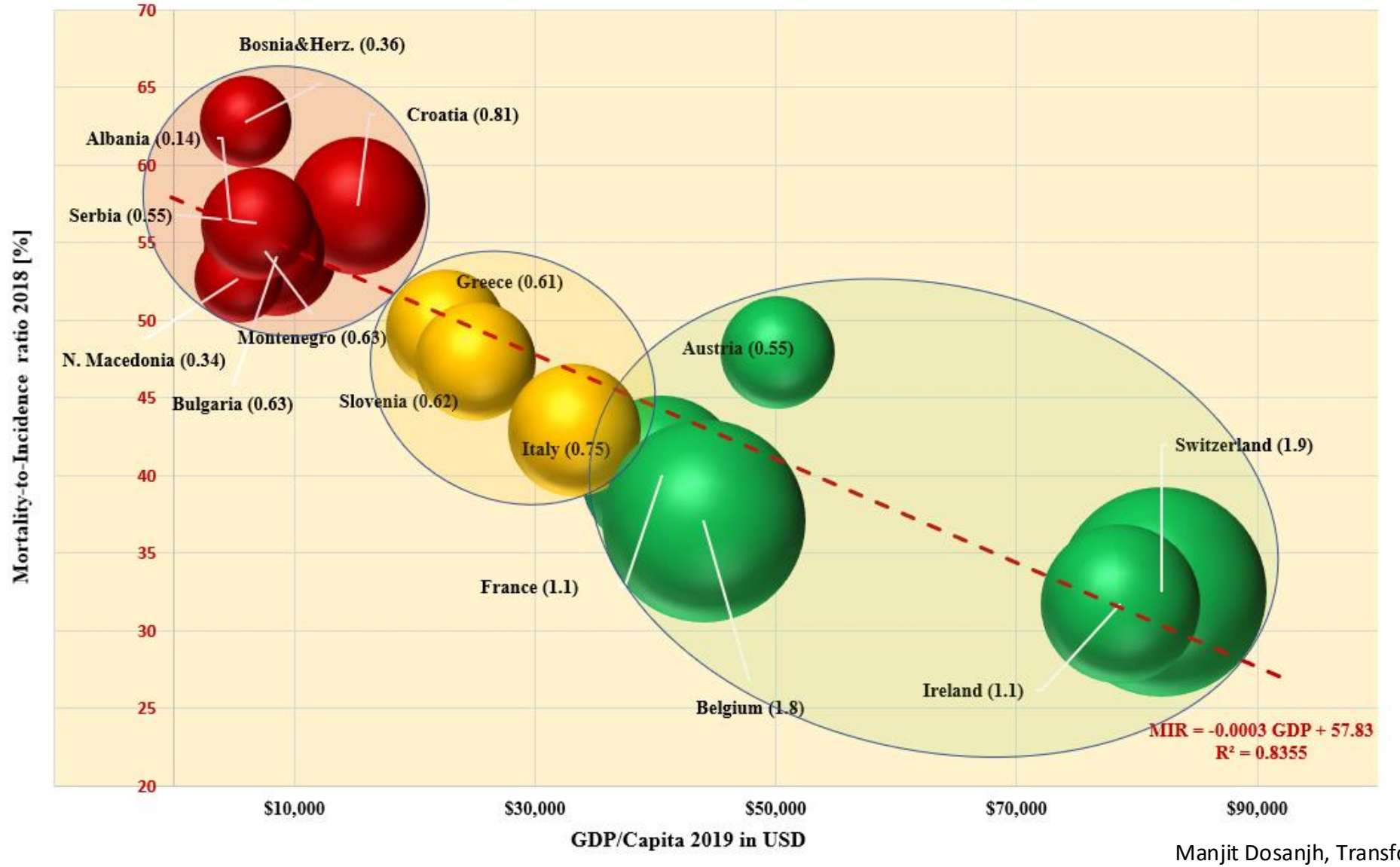




How successfully one country detects cancer? Mortality to Incidence ratio

Manjit Dosanjh, Mimoza Ristova et al, Availability of technology for managing cancer patients in the SEE region . *Clinical and Translational Radiation Oncology 2022, Vol 34, 57-66.* https://doi.org/10.1016/j.ctro.2022.03.004

Cancer Mortality to Incidence as function of GDP and RT equipment



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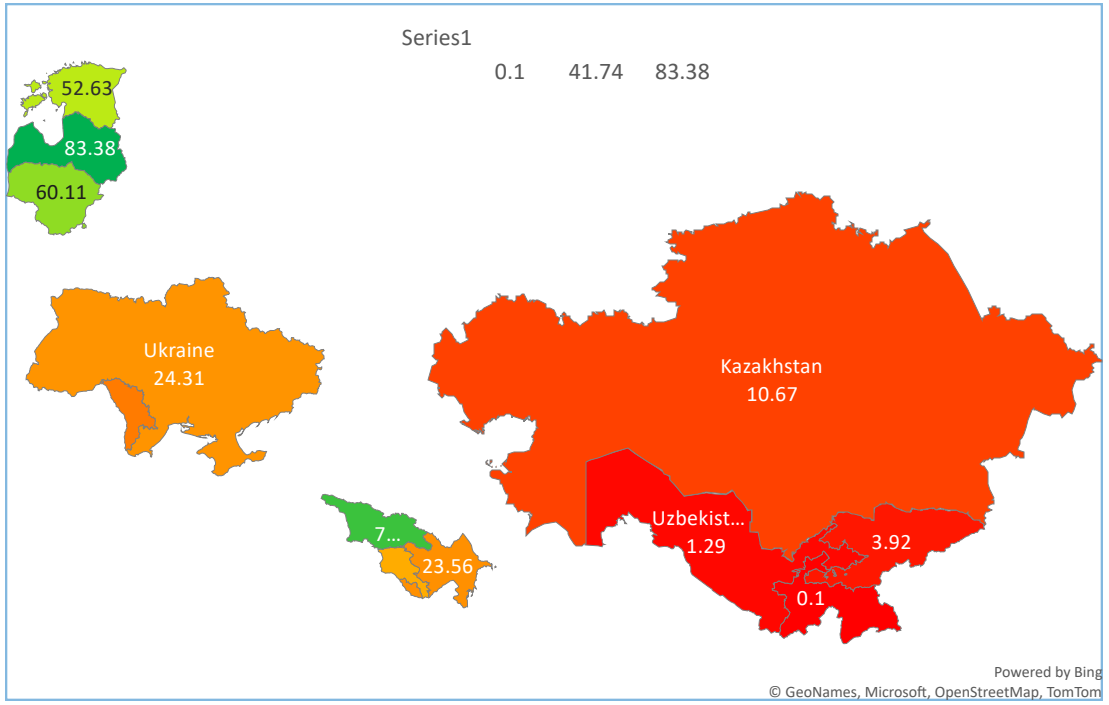
Dependence of the MIR on the GDP per capita and the density of conventional RT equipment. The radius of the spheres is proportional to the density of RT equipment per 100,000 population in the respective countries.

Access to Radiotherapy Technologies (ART) Study *(in press)*

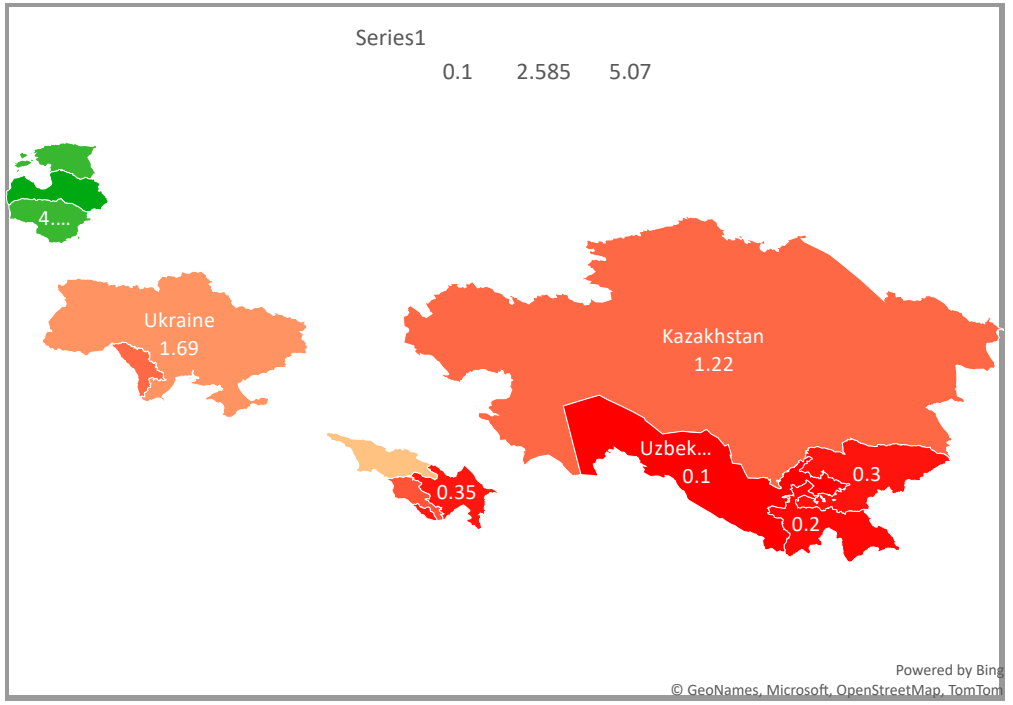
- Current status of RT in all former Soviet Union countries
- Understanding the challenges
- How to meet the challenges

Shortages and challenges are not only in Linacs

Number of total imaging equipment per 1000 000 population



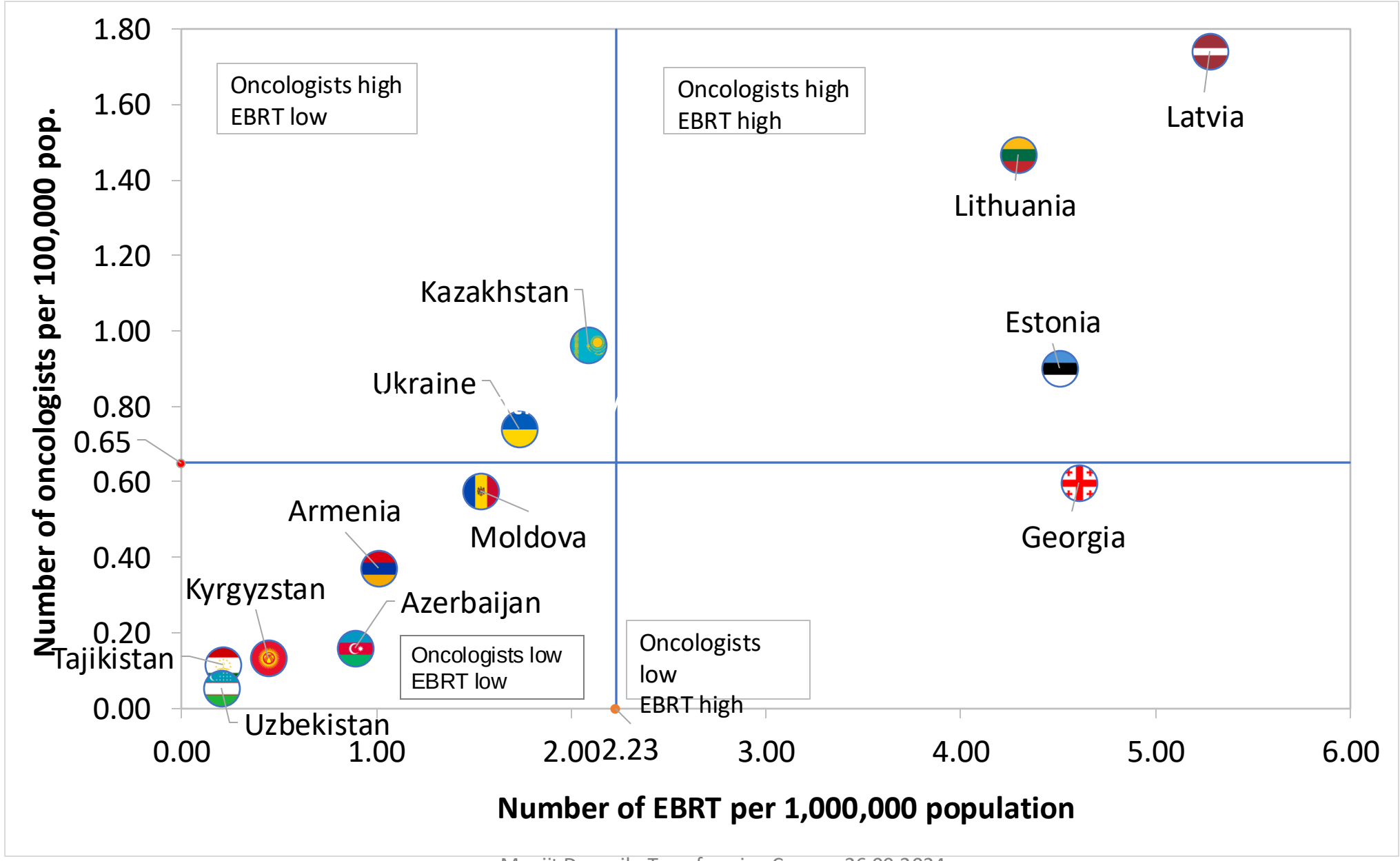
Experts per 100,000 inhabitants



Access to Radiotherapy Technologies Study (ART) in Former Soviet Union countries (Armenia, Azerbaijan, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Tajikistan, Ukraine and Uzbekistan)

Manjit Dosanjh, Transforming Cancer, 26.09.2024

Showing the countries by available EBRT and oncologists



Current status of RT

- Current Linacs provide very good treatment both in terms of technical capability and throughput.
- However current LINAC technology is **complex, labour intensive,** and **expensive** to acquire, install, operate and service
- Linac technology requires **strong, robust** and **reliable infrastructure** (power, clean water, supply chain etc.) to operate
- Many Linacs are purchased or deployed in Africa and LMICs without sufficient **training.** Many are never used or not close to their capacity
- Linac **servicing** can be slow and very expensive. Service contracts are expensive and not always purchased. Long down times (months or more).
- Can we use technology developments to address the current challenges and make RT more widely available?

Current Challenge: how to go from limited radiotherapy to high quality radiotherapy globally and in LMIC

Medical Linacs for challenging environments

- 1st Design Characteristics of a Novel Linear Accelerator for Challenging Environments, November 2016, CERN
- 2nd Bridging the Gap Workshop, October 2017, CERN
- 3rd Burying the Complexity Workshop, March 2018, Daresbury

- 4th Accelerating the Future Workshop, March 2019, Gaborone

CERN

International Cancer Expert Corps
Partnering to transform global cancer care

Science & Technology Facilities Council | UK Research and Innovation

STELLA (Smart Technology to Extend Lives with Linear Accelerators)

Globally, there is an ENORMOUS gap in available radiation therapy ***without which*** cancer care is not possible.

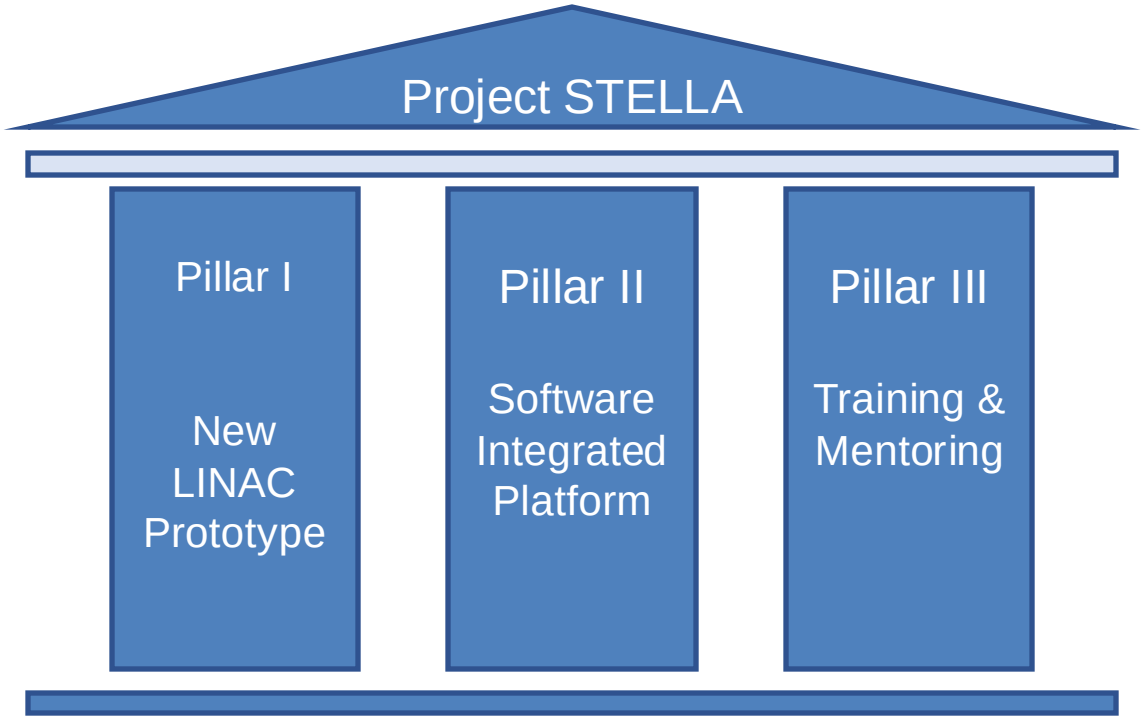
- **Current shortfall** of linear accelerators of at least **18,000**
- Commissioning one reasonably staffed unit per week ***would require a century to meet the current need.***

STELLA - A global partnership of the best clinicians, medical physicists and accelerator technologists globally

- Design a disruptive and innovative RT system to improve access to quality cancer care

[1]Zubizarreta , E., Van Dyk, J., & Lievens, Y. (2016). Analysis of Global Radiotherapy Needs and Costs by Geographic Region and Income Level. *Clinical Oncology*. https://doi.org/10.1016/j.clon.2016.11.011

STELLA: A Unique Collaboration



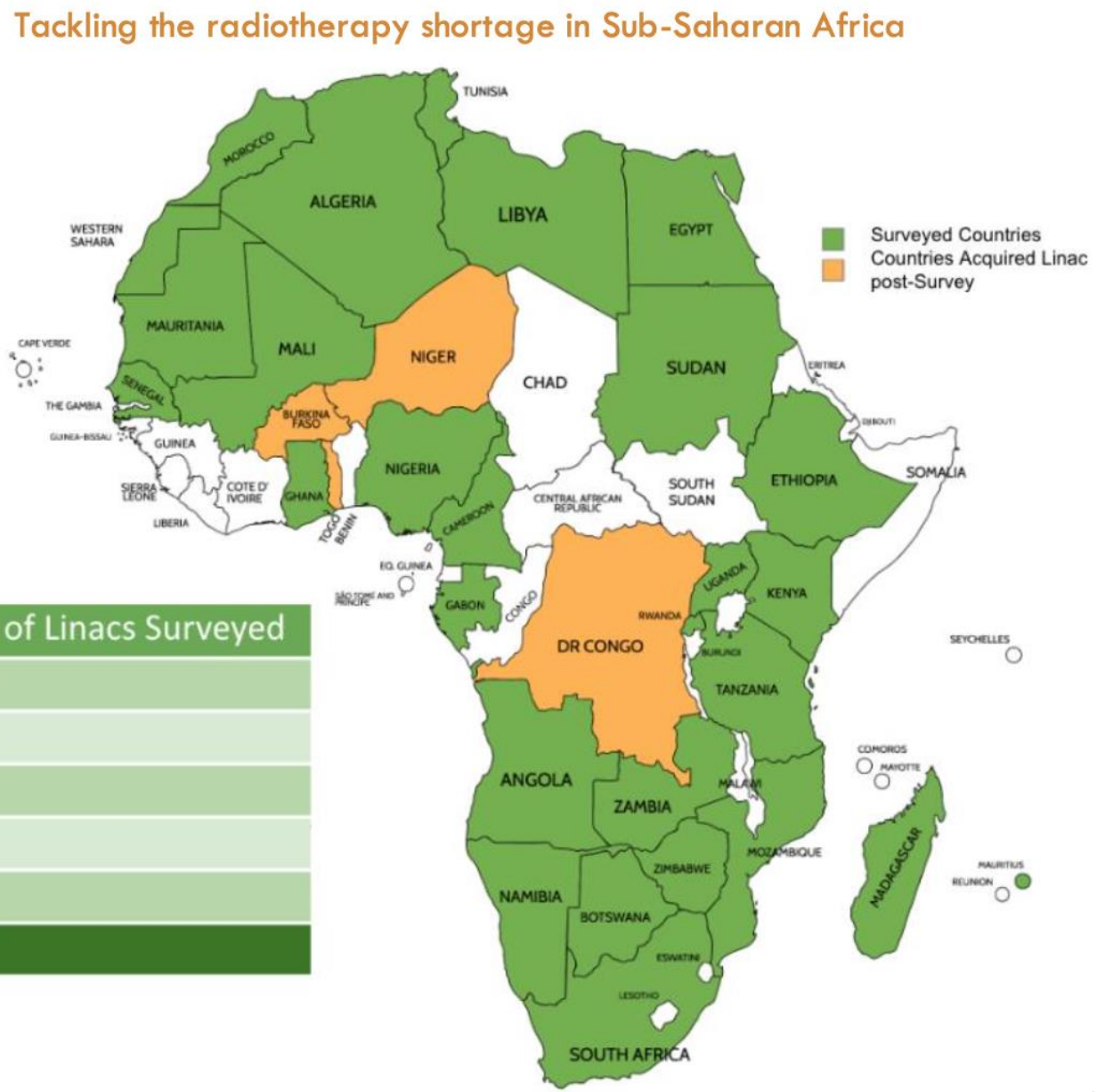
Pistenmaa, D., Dosanjh, M.K., Coleman C.N. et al. ***Perspective****: Changing the Global Radiation Therapy Paradigm: Design Characteristics of a Novel Linear Accelerator for Challenging Environments, June 2018, Radiotherapy and Oncology, DOI: 10.1016/j.radonc.2018.05.025*

STELLA SMART TECHNOLOGY TO EXTEND LIVES WITH LINEAR ACCELERATORS
UNIVERSITY OF OXFORD
International Cancer Expert Corps
Partnering to transform global cancer care
UKRI Science and Technology Facilities Council
Lancaster University
UNIVERSITY OF CAMBRIDGE
CERN

Innovative Technologies towards building Affordable and Equitable Global Radiotherapy (ITAR)

- **Define the problem**
- **Gather information** from African hospitals/facilities regarding challenges experienced in providing radiotherapy in Africa compare these to data from **HIC**.
- **Identify** the challenges from those who live with them day-to-day
- **Create design specifications** for a radiotherapy machine to meet these challenges for an improved design
- Assess applications of **ML, AI and use of cloud-computing** in African and LMIC settings
- Create **conceptual design report** for the radiotherapy system to enable technical design and prototyping in next phase

STELLA questionnaire for defining problem

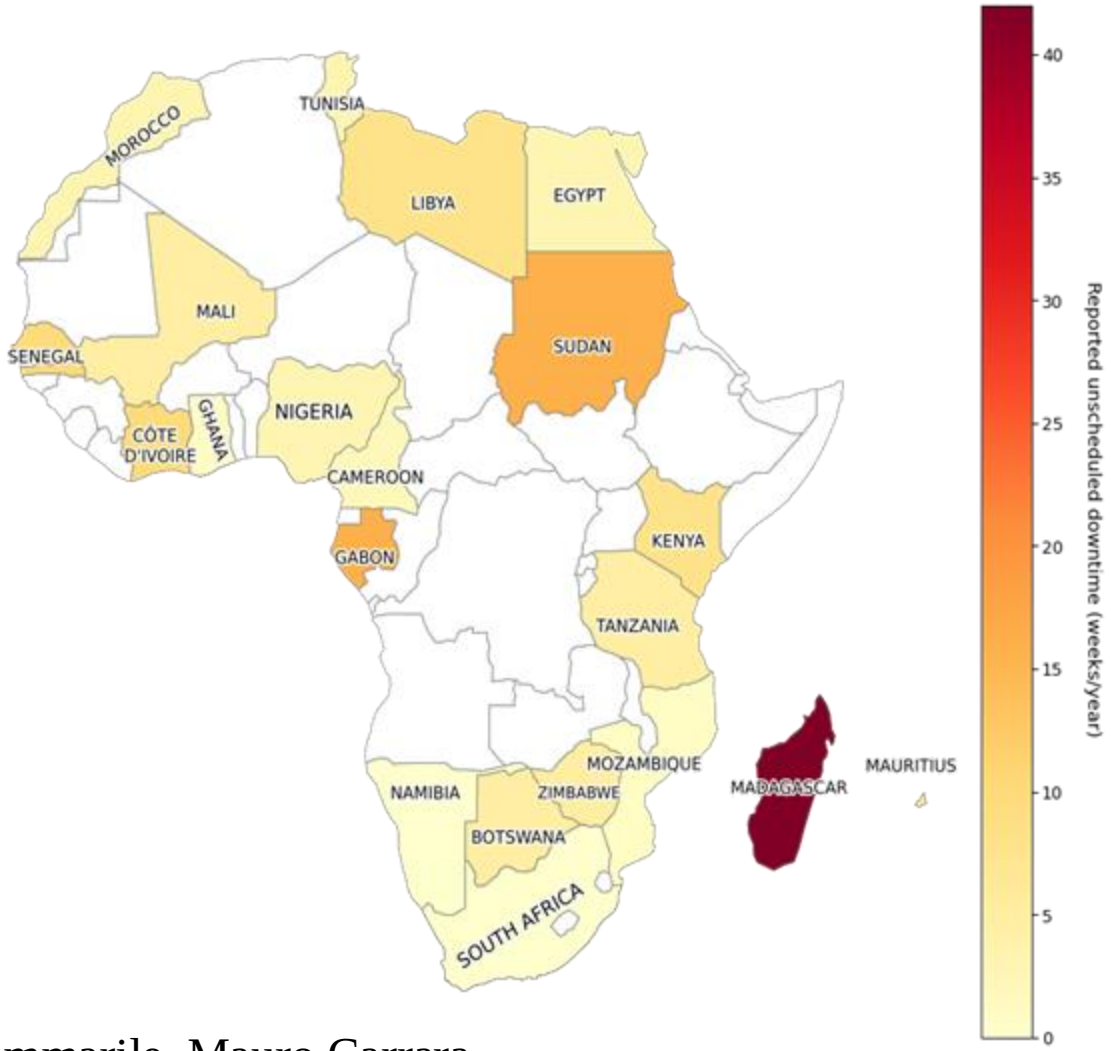


Country/Region	No. of Linacs Surveyed
UK	25
USA	14
Canada	11
Switzerland	2
Jordan	4
Africa	59

Map Showing Unscheduled Downtime

Figuring out what is Responsible for this Downtime?

- We investigated the impact of the various survey responses on machine downtime.
- Looked at univariate and multivariate analysis: observe how distributions of downtime vary for facilities grouped by question response.
- Also surveyed facilities in the UK, Canada, Switzerland and the USA, for comparison.



1. May Abdel-Wahab, Francesco Giammarile, Mauro Carrara

Established Initial data with the most vulnerable subsystems?

Subsystems

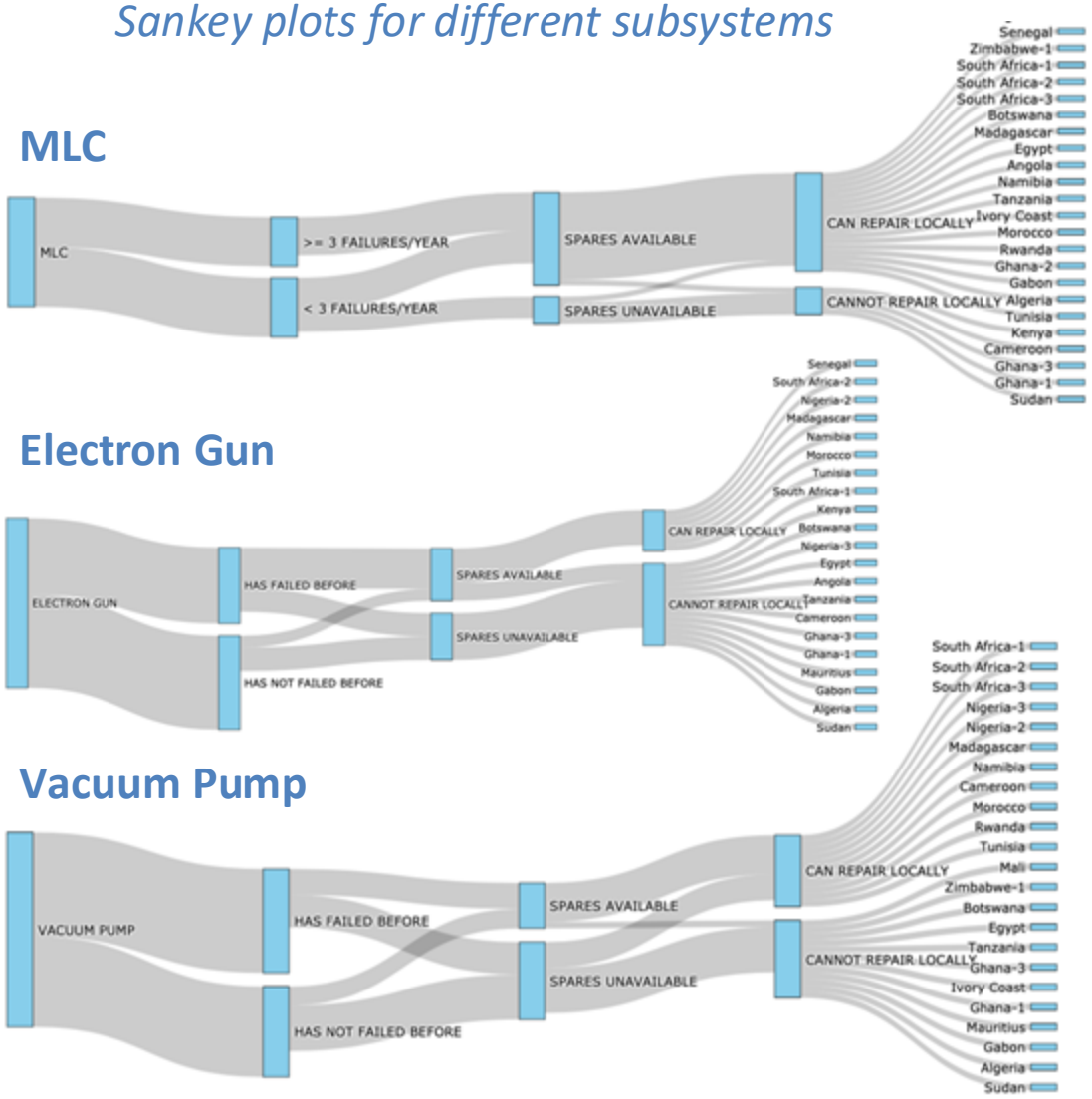
Observations

- **45%** of facilities experience **MLC** failures often. **77%** have spares. **78%** can repair locally.
- **44%** of facilities have experienced **electron gun** failure. **53%** keep spares. **33%** can repair locally.
- **53%** of facilities have experienced **vacuum pump** failure. **37%** keep spares. **48%** can repair locally.

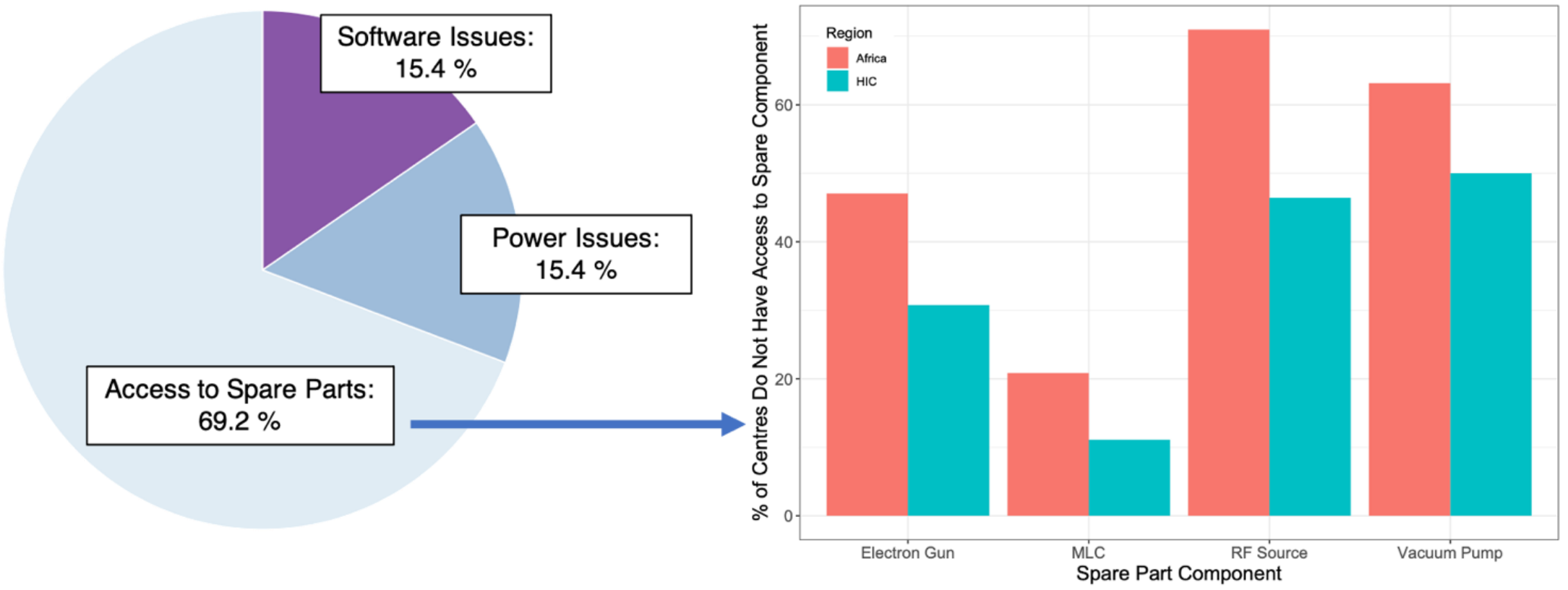
Take-aways

- If a facility experiences faults with a component, they are more likely to keep spare parts for it.
- If a facility keeps spare parts, they are more likely to have infrastructure in place to repair it.
- Ensure facilities have spares and can repair the part, before it has the chance to fail.
- Make fault diagnosis simple. A display/log on the machine will help staff easily identify faults.

Sankey plots for different subsystems

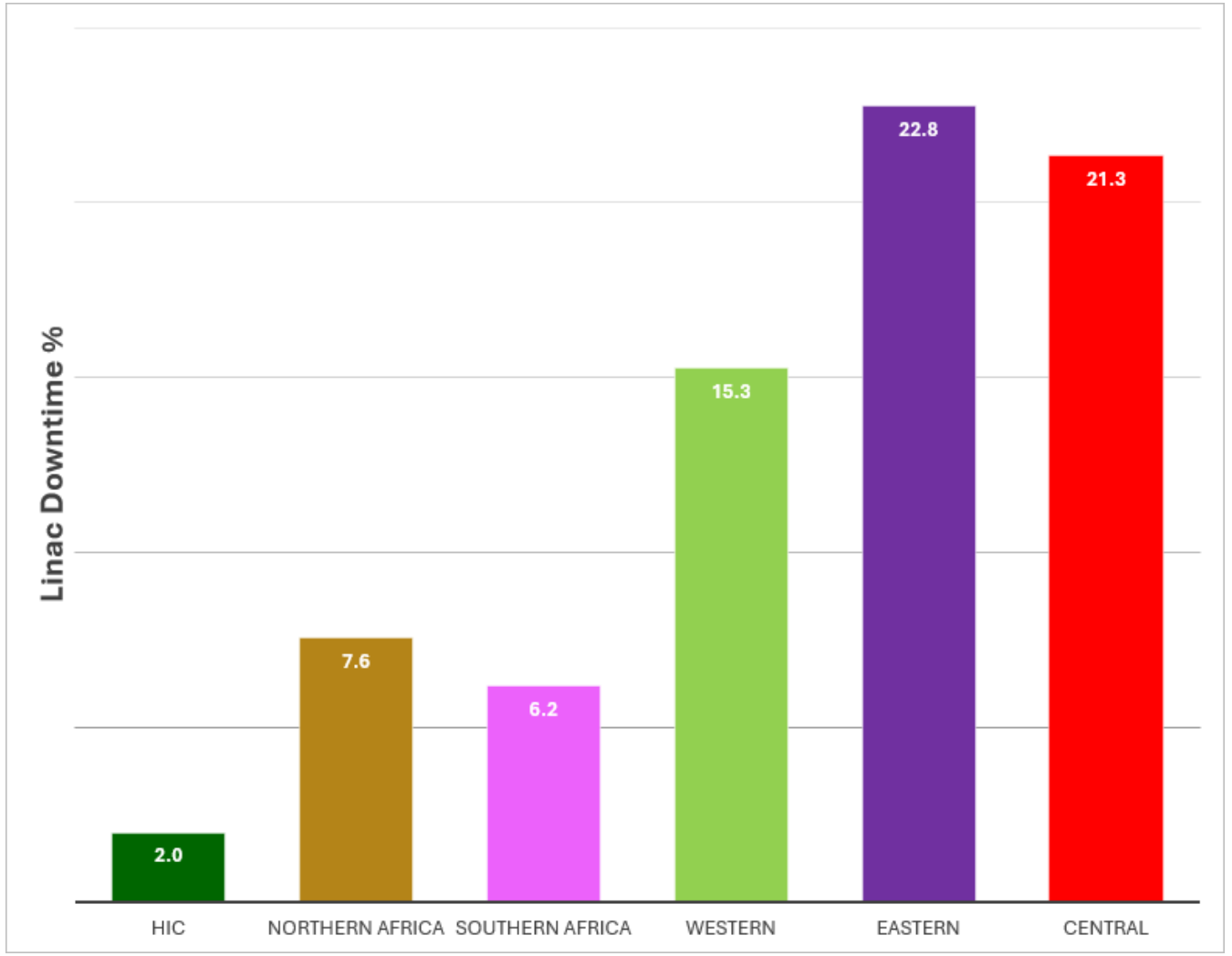


Main Reason for LINAC Downtime: Access to Spare Parts



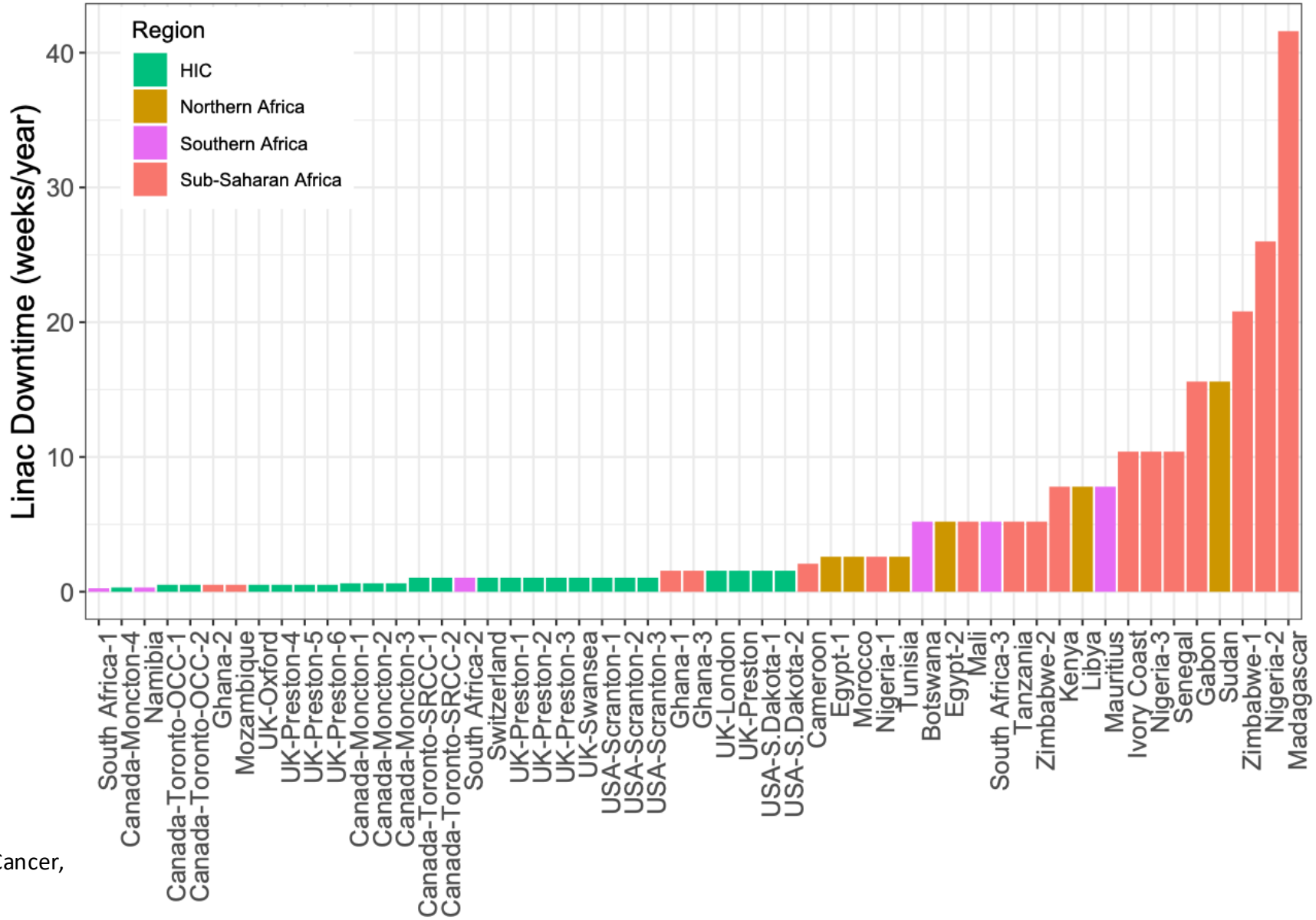
Dosanjh, M., Ige, TA., et al., 2024, Tackling the radiotherapy shortage, Medical Research Archives, [online] 12(8) doi.org/10.18103/mra.v12i8.5530

RT Machine Downtime in surveyed African Regions and HICs

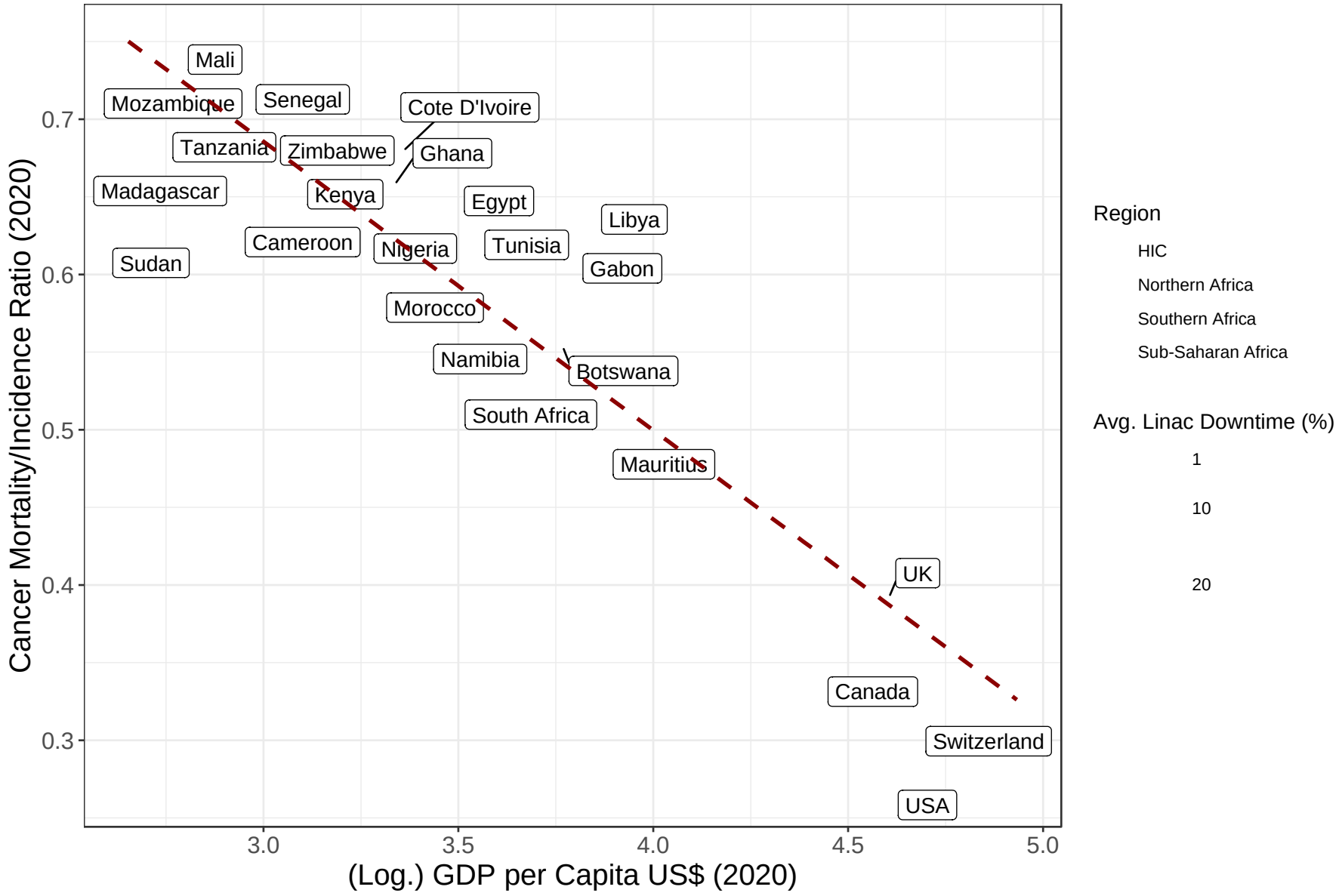


May Abdel-Wahab, et al. **Radiotherapy and theranostics: a *Lancet Oncology* Commission**. September 30, 2024 https://doi.org/10.1016/S1470-2045(24)00407-8

LINAC Downtime by Country



Impact of GDP per Capita and Linac Downtime and Cancer Mortality/Incidence



Where are we now?

- Gathered information from African hospitals/facilities regarding challenges faced in providing radiotherapy in Africa
- Identified the challenges with those who live with them day-to-day
- Created design specifications for a radiotherapy machine to meet these challenges for an improved design
- Assessing applications of ML, AI and use of cloud-computing in African and LMIC settings
- Created conceptual design report (Graham Burt and ITAR) for the radiotherapy system to enable technical design and prototyping in next phase
- **ICEC secured $1.75M funding from DOE**

ICEC-CERN STELLA Kick-off meeting: *"Re-engineering the Next Generation of Medical Linear Accelerators for Use in Challenging Environments"*

CERN and ICEC have agreed to leverage the DOE funding granted to ICEC for collaboration for the STELLA Project

Kick-off meeting involved the collaborations partners which included Cambridge, Lancaster, Oxford University, key leaders from LMICs (Botswana, Egypt, Ghana, Jordan, Kenya, Morocco, Nigeria, Senegal), IAEA experts, DOE-NNSA, other radiation oncologists.

STELLA Project Leader is Manjit Dosanjh,
3 Pillar Coordinators: LINAC: Steinar Stapnes (CERN); Software: Raj Jena (University of Cambridge); Training & Mentoring Nina Wendling (ICEC)

Meeting provided an update on the progress of STELLA, overview and challenges, expected deliverables for this phase of the project, brainstorming and coordination of the efforts going forward

Ultimate Goal for STELLA Project

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- Linacs must be: Robust, modular, reliable and simple to use machines

- Are affordable
  - ✓Reduce Capital cost
  - ✓Reduce Operating costs
  - ✓Reduce Service and Maintenance costs
  - ✓Reduce number of experts needed
  - ✓Increase number of treated patients per year
- Build expertise and capacitance
- Imaging is key since before treatment one has detect the cancer

Improving access for all cancer patients globally

Global goals for transforming cancer treatment and care for all

- Economic cost and health burden of cancers are distributed unevenly across cancer types and across countries.
- Despite the tremendous progress that has been made in the early detection of cancers and the treatment and care of cancer patients there are still major disparities in cancer treatment outcomes not only between high and low-income regions of the world, but also within countries.
- Improving cancer outcomes needs a multifaceted approach:
  - Registries, data records, standardized reporting, & infrastructure
  - Prevention, education, raising awareness
  - Screening, diagnosis, & treatment
  - Innovation and improving research resulting in more affordable and equitable access
  - Capacity building, enhancing and retaining workforce

Where someone lives should not determine whether they live (UICC)

Thank You for Listening

Power of seeing and understanding the challenges togetherand making STELLA a reality

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