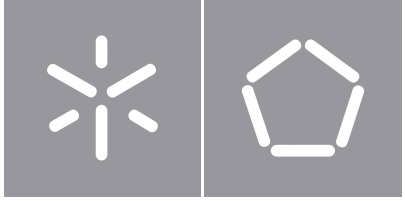
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Promoting Science Growth in Developing Countries: An Open Science Model for Mozambique

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University of Minho
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Promoting Science Growth in Developing Countries: An Open Science Model for Mozambique

PhD Thesis
PhD in Informatics

Thesis supervised by
Maria Solange Pires Ferreira Rito Lima
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Statement of Integrity

I hereby declare having conducted this academic work with integrity.

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University of Minho, Braga, september 2023

Marangaze Joaquim Munhepe Mulhanga

Abstract

In developing countries, deploying National Research and Education Networks (NRENs) infrastructures is viewed as a determining step for fostering science and education. In Africa, several NRENs initiatives appeared, having as critical success factors: (i) NREN deployment coverage; (ii) NREN sustainability policies; and (iii) the services provided to the enrolled community. Regarding Mozambique, after an initial period with significant difficulties, the Mozambique Research and Education Network (MoRENet) expanded to integrate nearly 160 institutions in the country, although connectivity is the only service provided. Despite the initiatives taken so far, for instance, in science sharing and distance learning, they lack a more comprehensive view on how to steadily stimulate science growth in the country.

It is in this context that the motivation for the present work lies, being the main objective defined as devising an evolutive and sustainable model for promoting science growth in Mozambique, which considers and adapts initiatives and best practices worldwide to the scientific and higher education ecosystem of the country. The proposed model targets and interrelates the contexts of open science, science management, distance learning, and technological infrastructures supporting science and education.

To sustain the proposed model, the research work carried out: discusses the NRENs panorama in Africa and Mozambique, and analyzes the challenges inherent to providing sustainable services for the NRENs academic and research community; explores and contextualizes successful Open Access (OA) initiatives and directives in the framework of developing countries; identifies the barriers and weaknesses for the improvement of the Mozambican higher education system; and stresses the role of MoRENet and international e-learning collaborations to mitigate the digital divide in education. Finally, proposals for the effective deployment of OA and distance learning strategies to overcome the identified challenges are presented. The thorough debate on the above-mentioned aspects and the proposal for open science in Mozambique are also expected to improve the awareness of science vectors in other developing countries, promoting their development both scientifically and socially.

Keywords NRENs, Open Science, Open Access, Distance Learning, e-Learning, Higher Education, Science and Technology, Developing Countries, Africa and Mozambique

Resumo

Nos países em vias de desenvolvimento, a implantação de infraestruturas de Redes Nacionais de Ensino e Investigação (*National Research and Education Networks* - NRENs) é vista como um passo determinante para fomentar a ciência e a educação. Em África surgiram várias iniciativas de NRENs, tendo como fatores críticos de sucesso: (i) a área de implantação das NRENs; (ii) as políticas de sustentabilidade; e (iii) os serviços prestados à comunidade envolvida. Relativamente a Moçambique, após um período inicial com dificuldades significativas, a Rede de Ensino e Investigação de Moçambique (*Mozambique Research and Education Network* - MoRENet) expandiu-se para integrar cerca de 160 instituições no país. No entanto, as iniciativas tomadas até agora, por exemplo, no acesso à ciência e no ensino à distância, carecem de uma visão mais abrangente sobre como estimular de forma constante o crescimento da ciência no país.

É neste contexto que assenta a motivação do presente trabalho, sendo o seu objetivo principal a conceção de um modelo evolutivo e sustentável de promoção do crescimento da ciência em Moçambique, que considere e adapte as iniciativas e melhores práticas mundiais ao ecossistema científico e de ensino superior deste país. O modelo proposto visa e inter-relaciona os contextos de ciência aberta, gestão científica, ensino à distância e infraestruturas tecnológicas de apoio à ciência e à educação.

Para sustentar o modelo proposto, o trabalho de pesquisa realizado: discute o panorama das NRENs em África e Moçambique, analisando os desafios inerentes à prestação de serviços sustentáveis; explora e contextualiza iniciativas e diretrizes bem-sucedidas de Acesso Aberto (*Open Access* - OA); identifica as barreiras e fragilidades para a melhoria do sistema de ensino superior moçambicano; e destaca o papel da MoRENet e das colaborações internacionais de e-learning para mitigar a divisão digital na educação. Por fim, são apresentadas propostas para a implantação efetiva de estratégias de OA e ensino à distância para superar os desafios identificados. O debate aprofundado dos aspetos acima mencionados e a proposta de ciência aberta em Moçambique permitirão ainda sensibilizar outros países em vias de desenvolvimento para os vetores da ciência, promovendo o seu desenvolvimento tanto cientificamente como socialmente.

Palavras-chave NRENs, Ciência Aberta, Acesso Aberto, Ensino à Distância, e-Learning, Ensino Superior, Ciência e Tecnologia, Países em Desenvolvimento, Africa e Mozambique

Contents

1 Introduction **1**

1.1 Motivation and objectives . . . 2

1.2 Research methodology . . . 5

1.3 Summary of main contributions . . . 6

1.4 Dissertation layout . . . 8

2 Open Access and Science Management **10**

2.1 Open Access initiatives and strategies . . . 10

2.1.1 Publications and repositories . . . 11

2.1.2 Workflows . . . 12

2.2 Open Access policies . . . 13

2.2.1 From the Horizon 2020 to Horizon Europe . . . 15

2.2.2 Dissemination and Data Management Plan . . . 16

2.2.3 Intellectual Property challenges . . . 18

2.3 Open Data movement and directives . . . 20

2.3.1 From storage to curation . . . 23

2.3.2 Data repositories . . . 24

2.4 Research Information Systems and OA . . . 25

2.4.1 CRIS . . . 26

2.4.2 New trends for CRIS . . . 28

2.5 Summary . . . 30

3 Technological Infrastructures Supporting Science and Education **31**

3.1 NREN concept and components . . . 31

3.1.1 Backbone infrastructure . . . 32

3.1.2 Access network or last mile . . . 33

3.1.3 International connectivity . . . 33
3.2 NRENs advanced services . . . 34
3.2.1 Organization model . . . 34
3.2.2 Distance education: e-Learning and Podcast . . . 35
3.2.3 e-Learning perpectives . . . 36
3.3 Summary . . . 38

4 Portugal and Africa Initiatives and Collaboration 39
4.1 NRENs and OA: Portugal as a Case Study . . . 39
4.1.1 B-on – The Digital Library . . . 39
4.1.2 RCAAP – The National Repository . . . 44
4.1.3 Educast service . . . 46
4.2 NRENs and OA in the African context . . . 47
4.2.1 NRENs . . . 47
4.2.2 Accessing knowledge . . . 50
4.2.3 e-Learning initiatives . . . 54
4.3 Summary . . . 55

5 Mozambique Scientific Ecosystem 56
5.1 Strategic plan . . . 56
5.2 Higher education . . . 57
5.2.1 Scientific research and production . . . 60
5.2.2 Accessing scientific literature . . . 61
5.3 SABER - The National Repository . . . 62
5.4 OA journals: the case of RC-UEM . . . 63
5.5 e-Learning as an education alternative . . . 64
5.5.1 National initiatives . . . 64
5.5.2 Exploring international collaboration . . . 65
5.5.3 Discussing the challenges . . . 66
5.6 Technological infrastructures . . . 67
5.6.1 The telecommunication sector . . . 67
5.6.2 MoRENet - Mozambique NREN . . . 68
5.6.3 Providing sustainable services to MoRENet community . . . 71

5.7 Summary . . . 73

6 Proposed Model for Open Science in Mozambique 75

6.1 Science growth interrelated vectors . . . 75
6.2 Higher Education . . . 77
6.3 Accessing knowledge . . . 79
6.4 Scientific research . . . 80
6.5 Open Access . . . 80
6.5.1 Proposed Open Science services . . . 82
6.6 e-Learning and Podcast . . . 85
6.7 MoRENet . . . 86
6.8 Summary . . . 87

7 Challenges and Next Steps 88

7.1 Africa . . . 88
7.2 Mozambique . . . 93
7.3 Summary . . . 101

8 Conclusions and Future Work 102

8.1 Summary . . . 102
8.2 Reviewing results and contributions . . . 103
8.3 Prospect for future work . . . 106

List of Figures

1 Repositories by country in the world 12
2 Autoarchive workflow 13
3 Open Access decision process 17
4 Scientific data 22
5 CRIS ecosystem 27
6 The CERIF model 29

7 Organizational view of NRENs supporting science 34
8 e-Learning multiple perspectives 37

9 B-on: service entities 40
10 B-on: a cycle of five processes 42
11 National repository model - RCAAP 46
12 African NRENs 49

13 Detailed Mozambique higher education evolution (available from 2004 - 2010) 59
14 Mozambique research output (available from 2005 - 2013) 61
15 Annual distribution of documents in SABER repository 63

16 Vectors of the Open Science model 76
17 Open Science services in Mozambique 84

List of Tables

1 Repositories in Africa 51
2 Journals in DOAJ 52
3 Journals in AJOL 53
4 Policies and mandates 54
5 Full-time teachers (2004 and 2017) 58
6 Students (2004 and 2017) 59
7 MoRENet phases 70
8 MoRENet infrastructure 72

List of Acronyms

AAS African Academy of Sciences

AJOL African Journals OnLine

APAN Asia Pacific Advanced Network

ASREN Arab States Research and Education Network

AU African Union

BOAI Budapest Open Access Initiative

B-on Biblioteca do Conhecimento Online

CAD Centre for Academic Development

CERIF Common European Research Information Format

CERN The European Organization for Nuclear Research

ConfOA Conferência Luso-Brasileira de Ciência Aberta

CPLP Comunidade dos Países de Língua Portuguesa

CRIS Current Research Information System

CTT Correios, Telégrafos e Telefones

DMP Data Management Plan

DOAJ Directory of Open Access Journals

DOI Digital Object Identifier

EC European Commission

ECTIM Estratégia para a Ciência, Tecnologia e Inovação de Moçambique

EIFL Electronic Information for Libraries

EPNCT Empresa Parque Nacional de Ciência e Tecnologia

EIFL Electronic Information for Libraries

EU European Union

FAIR Findable, Accessible, Interoperable and Re-usable

FCCN Fundação para a Computação Científica Nacional

FCT Fundação para a Ciência e a Tecnologia

FP7 Seventh Framework Programme

FSAU Fundo de Serviço de Acesso Universal

GIS Geographic Information System

GSM Global System Mobile

HD High Definition

HEI Higher Education Institutions

HGP Human Genome Project

ICT Information and Communications Technology

INASP International Network for the Availability of Scientific Publications

INCM Instituto Nacional de Comunicações de Moçambique

IRU Indefeasible Right of Use

ISPs Internet Service Providers

IXP Internet Exchange Point

LHC Large Hadron Collider

MCT Ministério da Ciência e Tecnologia

MedOAnet Mediterranean Open Access Network

MoRENet Mozambique Research and Education Network

MOSTIS Mozambique Science, Technology and Innovation Strategy

MOZIX Mozambique Internet eXchange

MST Ministry of Science and Technology

NEH National Endowment for the Humanities

NIH National Institutes of Health

NOC Network Operations Center

NRENs National Research and Education Networks

NRF National Research Fund

NRS National Research System

NSF National Science Foundation

OA Open Access

OAI Open Archives Initiative

OAI-PMH OAI Protocol for Metadata Harvesting

OARE Online Access to Research in the Environment

OECD Organization for Economic Co-operation and Development

OpenAIRE Open Access Infrastructure for Research in Europe

OpenDOAR Directory of Open Access Repositories

ORCID Open Researcher and Contributor ID

OSTP Office of Science and Technology Policy

PESD2 Programa de Ensino Secundário à Distância 2

PoPs Points of Presence

RD Research and Development

RCAAP Repositórios Científicos de Acesso Aberto de Portugal

RCTS Rede Ciência, Tecnologia e Sociedade

RENATER Réseau National de Télécommunications pour la Technologie, l'Enseignement et la Recherche

ROAR Registry of Open Access Repositories

SADA South African Data Archive

SARI Serviço de Alojamento de Repositórios Institucionais

SDUM Serviços de Documentação da Universidade do Minho

SPSS Statistical Package for the Social Sciences

STISM Science, Technology and Innovation Strategy of Mozambique

TDM Telecomunicações de Moçambique

TMcel Moçambique Telecom

U.S. United States

UASF Universal Service Access Fund

UB University of Botswana

UCM Universidade Católica de Moçambique

UEM University Eduardo Mondlane

ULM University of Lourenço Marques

UM University of Minho

UNESCO United Nations Educational, Scientific and Cultural Organization

UNF Universal Numerical Fingerprint

USDA U.S. Department of Agriculture

VM Vodacom Mozambique

VPN Virtual Private Network

WACREN West and Central African Research and Education Network

WSIS World Summit on the Information Society

Chapter 1

Introduction

In today's society, the stage of science and technology of a country evinces its developing level. In this sense, despite being rich in natural resources, which could be considered an advantage for economic and social progress, the development of most African countries is still immature, largely due to the lack of qualified human resources, the economic dependence, and the lack of a consistent system for managing science, technology and higher education.

National Research and Education Networks (NRENs) play an extremely important role in this context, being supported by non-profit organizations whose mission is to provide advanced services to the research community and higher education. In the absence of a single model that can be applied to all NRENs, as well as its constitution and funds, creating a model of NREN must meet the reality of each country in coordination and collaboration at regional and international levels. Deploying NRENs infrastructures has been an important step for fostering science and technology in developing countries, however, to become fruitful, advanced services oriented to science and technology management need to be provided to the academic and research community.

A relevant service concerns the management of the amount of information related to scientific knowledge, which has grown exponentially on the Internet. The communications paradigm of next-generation networks resulted in a new environment and a new challenge for science, facilitating not only the dissemination and sharing of knowledge but also new models of doing science. The available technological tools and the Open Access (OA) paradigm enable broader cooperation, transparency and visibility of scientific outcome [1, 2, 3]. The production of scientific documents, the collaboration between researchers, the publication of research results, and the management of bibliometric data are examples of the application of Information and Communications Technology (ICT) in the scientific field. Open Science covers three pillars: OA, Open Research Data, and Open Scholarly Communications [4]. The present work addresses the first two pillars in the context of the canonical model of open science.

Facing the above, it is important to look at international directives and the experience of countries that

are at the forefront in terms of the provision of connectivity and advanced services to the research and academic community. As example, Portugal is recognized as a successful case, due to the implementation of the national scientific OA repository (*Repositórios Científicos de Acesso Aberto de Portugal* - RCAAP) and the Online Knowledge Library (*Biblioteca do Conhecimento Online* - B-on). RCAAP and B-on are services supported by *Fundação para a Ciência e a Tecnologia* - FCT, the national entity responsible for managing the Portuguese NREN, which provides high-speed connectivity and advanced services to academic and research institutions. These services have proved to be relevant to the production, sharing and dissemination of scientific production in the country.

Focusing on Mozambique, the national repository SABER and the Mozambique Research and Education Network (MoRENet) are projects with the aim of efficiently sustaining the work of the Mozambican academic and research community. MoRENet is the result of ICT actions taken by the Mozambican government. The adoption of an ICT policy in 2000 as a framework for the development of an information society in the country, defined as main objectives combating poverty and improving Mozambicans' life conditions. One relevant aspect of this policy is ensuring the production and access to knowledge, in order to turn the country into a relevant and competitive partner in the global information society. Following this ICT policy, the Strategy for Science, Technology and Innovation of Mozambique (*Estratégia para a Ciência, Tecnologia e Inovação de Moçambique* - ECTIM) was adopted, which *"aims to establish a framework conducive to the achievement of strategic objectives and programs that promote the development of an integrated system of science, technology and innovation"*. Despite the efforts conducted so far, these initiatives achieved limited impact, and much work has still to be done to foster knowledge growth through NRENs in Mozambique.

1.1 Motivation and objectives

African developing countries are capturing serious attention nowadays. The combination of substantial available resources with the under-developing status of important social and technological sectors attracts the attention of both commercial and non-profit institutions. Within the area of knowledge management, many initiatives have emerged, aiming to foster the growth of human and technological resources that improve consistently scientific research, promoting the development of the country at both scientific and social levels.

Nowadays, developing strategies for sharing knowledge is viewed as a major issue for the progress of societies. One of the major impairments in the access to scientific information is that the full contents are

not always freely available. Scientific journals serve as tools for disseminating research results in different fields of knowledge, however, the monopoly of commercial scientific publishers requires from institutions substantial financial and operational efforts in the acquisition of scientific literature.

Thus, in developing countries, due to economic restrictions, the access to scientific publications depends largely on the support of some international bodies providing the access, production and use of research information and knowledge. Even in these cases, not all institutions have digital libraries and, in many cases, network connectivity to sustain the available digital services is still deficient.

Another way to access and divulge knowledge, especially advantageous, is through OA repositories. Developing OA repositories enables the visibility, accessibility and dissemination of the scientific production of a country. The United States (US) government, through the Office of Science and Technology Policy, and the European Council recognized the importance of OA to the academic and scientific community, and released guidelines sustaining that the results of publicly funded research projects should be available through an open and unrestricted access.

In the African context, there are still many challenges to implement digital libraries and OA, both regarding the access to scientific content and network connectivity. The high cost of broadband access and the lack of a national and international network infrastructure based on fiber-optic are limiting factors. Despite the inherent difficulties in deploying NRENs in Africa, several initiatives have been promoted, being UbuntuNet Alliance one of the most important. Interconnecting African NRENs and sub-Saharan Africa in an international high-capacity network through GÉANT, the European Research and Education Network backbone, is the main goal of this alliance. Achieving this goal through Africaconnect project will enable the African research and education community to collaborate and participate effectively in NRENs mission at a global level. International organizations and collaborations supporting and promoting the access and sharing of scientific publications also play a relevant role in fostering knowledge in developing countries.

In Mozambique there are several ongoing initiatives and projects for developing research and education, namely the initiatives of University Eduardo Mondlane (*Universidade Eduardo Mondlane* - UEM) in the OA field and the project MoRENet within the Ministry of Science, Technology and Higher Education (*Ministério da Ciência, Tecnologia e Ensino Superior* - MCTES). Despite the efforts, the initiatives and strategic plans devised so far haven't yet achieved their full potential, being crucial to understand the multidimensional aspects that may impaired their success. In this context, the study of the challenges and constraints for deploying effective communications infrastructures and advanced services targeting the Mozambique higher education and research community needs is still an open issue.

Considering that managing science and technology requires understanding the scientific and techno-

logical system of a country, without losing sight of its general framework and relationships, it is crucial to cover national strategies for science and technology, framing them by successful initiatives worldwide. Having this in mind,

the main objective of this work is to devise an evolutive and sustainable model for science growth in Mozambique, which considers the scientific and higher education ecosystem of the country. This model has as main target the contexts of open science, science management, distance learning, and technological infrastructures supporting science and education.

To achieve this goal, it is fundamental to raise and answer the following research questions:

- *Which are the main vectors to consider to foster the scientific development of Mozambique? Or, conversely, which are the main obstacles to this development?*

  Taking a broader perspective, the following questions also need to be addressed:

- *Which lessons and guidelines can be learned from the models of open access and science management adopted in developed countries*?
- *How can the scientific development of Mozambique be accelerated by taking advantage of recognized NRENs best practices worldwide*?
- *In which way do these guidelines and best practices have to be adapted to fit the reality of African countries, more specifically, Mozambique*?

In order to pursue the main objective stated above and answer the related research questions, a more detailed view over the problem to solve has led to the following objectives:

- identify and study the main issues and recent developments related to the problematic of OA and Science Management;
- contextualize and survey existing initiatives and deployments related to NRENs and advanced services, such as distance learning;
- study international initiatives and success cases in OA and NRENs fields, such as the Portuguese experience, and NRENs alliances and projects in Africa;
- understand and characterize the Mozambique ecosystem and the main vectors to consider to foster science growth in the country;

- conceive and debate a new model for science growth in Mozambique, sustainable and focused on worldwide open science directives;
- identify and discuss the main challenges that may arise from the deployment of this model in Mozambique, without losing sight of other developing countries' perspectives.

By studying and interrelating the mentioned aspects it is expected that the proposed science model provides new insights for promoting science growth in Mozambique, and in developing countries in general.

1.2 Research methodology

The research methodology to achieve the main objective of this work includes several steps in some way exposed in the list of objectives defined above. First, considering the main areas of related research, a survey of the relevant literature and worldwide initiatives covering the main developments in each of these areas is carried out. This research and literature review allows for a comprehensive analysis of the current state of the art in these areas, supporting the conceptual and practical decisions taken to devise an evolutive model for open science in Mozambique.

Secondly, for conceiving a model adjusted to Mozambique reality, it is crucial to define appropriate fieldwork steps. In particular, the following steps were considered:

- a 3-month internship at *Fundação para a Computação Científica Nacional* - FCCN, FCT Unit, in Portugal, to gain real knowledge of the functioning of an NREN and its services, which included face-to-face interviews with the heads of each department;
- a face-to-face interview with the head of the University of Minho (UM) library in Portugal;
- 4 phases of fieldwork in Mozambique which included face-to-face interviews and visits at the Ministry of Science and Technology;
- 2 face-to-face interviews with the general director of the *Instituto Nacional de Comunicações de Moçambique* (INCM), the Mozambican communications regulator;
- participation in conferences and forums, including a forum on the information society and the Luso-Brazilian Conference on Open Acces (ConfOA).

1.3 Summary of main contributions

This section summarizes the major contributions of this thesis, which will be further discussed in the final chapter. Taking into account the objectives defined above, these contributions are summarized as follows:

- taking worldwide OA initiatives and the Portuguese experience as case study, the work in [5] analyzes technical challenges and strategies for building open repositories supported by NRENs in the African context. The implementation of digital libraries and OA to scientific contents was further discussed in [3];

- considering Mozambique as the main target, [5] presents a study of: (i) existing national and international initiatives; (ii) MoRENet; and (iii) SABER repository. This study supported the proposal of a set of directives and policies for the development and sustainability of a common OA platform for scientific and academic national production;

- the work in [6] discusses the problematic of science growth in developing countries, focusing on the role of NRENs and OA repositories in expanding knowledge frontiers. By studying NRENs and OA initiatives worldwide, and taking the Portuguese experience as a case study, it was possible to identify the main difficulties and directions for the deployment and sustainability of OA repositories in the African context, more specifically in Mozambique;

- the proposal in [6] encourage the initial support of a common OA repository by MoRENet and envision the evolution of this repository into a meta-repository, following the expected expansion of scientific production in academic and research institutions in Mozambique;

- the study in [3] addresses aspects such as: i) the access to scientific literature through digital libraries; ii) OA initiatives regarding repositories and journals; (iii) the relevance of adopting OA policies and mandates; and (iv) the role of governmental and institutional strategies and initiatives in supporting science and technology. The discussion and directives advocated in this work also provide useful insights for identifying potential international cooperation synergies to sustain knowledge growth in developing countries;

- considering that in Mozambique, as in any developing country, the issues related to OA and Current Research Information System (CRIS) prove to be relevant and need to be analyzed carefully, the study in [3] discusses the new directives for managing science and stresses the importance of

NRENs and OA, making specific recommendations aiming at fostering the sharing and disseminating of the results of research conducted in Mozambique;

- taking Mozambique as a case study, [7, 8] discusses the problematic of science growth in developing countries and identifies hurdles and strategies for building OA repositories supported by MoRENet, and implementing technological platforms for managing science. This work also presents a first perspective of the evolutive open science service model, aiming at empowering the evolution of knowledge in Mozambique. This proposal was sustained by the study of international directives regarding NRENs and OA, CRIS trends, and the Mozambican science and education ecosystem;

- resorting to fieldwork carried out in Mozambique, involving relevant Mozambican institutions in the research arena, and based on the critical analysis of important national and international initiates in the field and their outcome, the work in [9, 10] provide an outlook of higher education and science in the country, discussing: i) the problematic of sharing and accessing scientific literature; ii) the evolution and role of the open access repository SABER; and (iii) the evolution of MoRENet, as the supporting network infrastructure for knowledge growth;

- having Africa as the main focus and, in particular, the technological and educational Mozambican ecosystem, the work in [11] discusses initiatives in the e-learning context that can provide clear inputs regarding the challenges and critical factors affecting success. In particular, a case study of the relevance of providing podcast services at NREN level is discussed, and quantitative evidence of the success of e-learning initiatives in Africa is presented. Through the debate of pertinent case studies and corresponding outcomes, the relevance of supporting podcasting and e-learning as NREN advanced services is stressed, aiming at facilitating the enrolment of academic and scientific institutions and enlarging the scope of the obtained results;

- the work presented in [12] detailed the panorama of NRENs in Africa and the role of projects such as AfricaConnect in providing sustainable distance learning services for the NRENs academic and research community. In particular, it contextualizes distance learning initiatives and directives in the framework of Mozambique and MoRENet, and the barriers and weaknesses for the improvement of the Mozambican higher education system. Finally, proposals for the effective deployment of distance learning strategies to overcome the identified challenges are discussed;

- the work presented in [13] discusses the NRENs panorama in Africa, with a particular focus on Mozambique, covering the technological steps behind NRENs deployment and the challenges to

provide relevant services to the enrolled community, in an encompassing and sustainable way. For this purpose, the technological and scientific ecosystem of Africa and Mozambique is analyzed, and the national and international synergies at NREN and higher education levels are identified. A service model for fostering e-learning and science sharing in Mozambique is here proposed.

1.4 Dissertation layout

This dissertation is structured in seven chapters addressing the research work accomplished facing the objectives outlined in Section 1.1.

In the present Chapter 1 - *Introduction* - the research area is introduced, highlighting current trends in OA and NRENs. The motivation for this thesis is justified and the main objectives of the work are defined. The main contributions of the work carried out are also summarized. The included dissertation layout provides a global view of the contents and organization of the full document.

In Chapter 2 - *Open Access and Science Management* - OA initiatives, and related promotion strategies and policies for OA self-archiving are discussed. The debate includes the challenges related to intellectual property and the directives related to research data repositories. CRIS concepts and trends as technological platforms for research management are also discussed in this chapter.

In Chapter 3 - *Technological Infrastructures Supporting Science and Education* - the motivation for adopting NRENs is introduced, centering the discussion on the evolution of NRENs, their components and supported services. Considering the relevance for developing countries, the support of distance learning services deserved special attention. Regarding technological issues, facing that to build an NREN it is essential to consider aspects that depend on each country's reality, concepts of: the national backbone; the access network or last mile; and the international connectivity are addressed.

In Chapter 4 - *Portugal and Africa Initiatives and Collaboration* - case studies related to the unrestricted access to scientific literature and NRENs are discussed. Being Portugal recognized as a successful case on OA deployment and NRENs supported services, such as podcast, the initiatives and strategies adopted in this country are surveyed. This chapter also discusses the experience and challenges of accessing knowledge and e-learning in African countries and the panorama of NRENs in Africa.

In Chapter 5 - *Mozambique Scientific Ecosystem* - the current science and technology situation in Mozambique, and the challenges and barriers in accessing scientific information are discussed. In more detail, this chapter presents and interrelates aspects involving the development of scientific research, covering the higher educational system and the distance learning initiatives, the national OA steps so far, the

challenges toward the evolution of science through MORENet, and the explored international collaborations. In summary, a debate of Mozambique as a case study is provided, presenting its technological and educational framework, along with the main vectors to consider for providing sustainable services in its NREN.

In Chapter 6 - *Proposed Model for Open Science in Mozambique* - considering the technological environment and the challenges that Mozambican institutions face in implementing national and institutional policies and mandates of OA, an evolutive and sustainable model for open science in Mozambique is proposed. This model is inspired in worldwide directives, the Portuguese national model, the African and Mozambican technological and scientific contexts, taking also advantage of the benefits of advanced services supported by NRENs. An introspective analysis of the proposed model is carried out, identifying its advantages and hurdles, and pointing out possible ways to overcome the last ones.

In Chapter 7 - *Challenges and Next Steps* - OA, e-learning, and NRENs issues in the context of Africa and Mozambique are further discussed, aiming at clarifying the main challenges and next steps to, in a sustainable perspective, overcome them.

In Chapter 8 - Conclusions - a summary of the present research work is presented, debating on to what extent the defined objectives have been accomplished. This chapter also highlights the main contributions of this thesis, pointing out future research directions for the work carried out.

Chapter 2

Open Access and Science Management

The debate on unrestricted access to academic and scientific literature has emerged mainly due to the limitations associated with the marketing of works published in scientific journals. Scientific journals are used as tools to disseminate research results in different fields of knowledge. The results of scientific work conducted by researchers, which are in most cases financed by funds or grants from the research institution, are submitted free of charge to scientific journals. Contrarily, the monopoly of commercial scientific publishers obliges the institutions' libraries to buy the same publications, a fact which motivated the Open Access (OA) movement [14] and OA repositories. The Open Research Data movement [14], although related to OA, has its own aim and agenda, being focused on the access to data collected and/or produced in the course of research activities, ensuring their preservation and share[1]. Regarding technological platforms for managing science, the CRIS [15] emerged to store and manage data related to the entire lifecycle of research, including science components and players.

The interest of developing countries in these paradigms is evident, as instantiating their concepts and directives in the science framing of developing countries will allow them to save years of progress. In this context, this chapter is devoted to surveying worldwide initiatives, strategies and policies in OA, Open Research Data and science management domains, as a way to gather a broad view of how open science can be consistently fostered and managed in Mozambique.

2.1 Open Access initiatives and strategies

Scientific OA repositories aim to provide unrestricted access to academic and scientific literature resorting to information systems that store and give access to data. Therefore, an OA repository is a collection of documents in electronic format, freely available to users through the Internet.

[1] Research data includes all records produced, obtained or used during the investigation process that can validate the results of the investigation. These can be text, image, video, audio, tables, questionnaire results, interviews, observations, simulations, experiments, artifacts, photographs, contributions to social networks, statistics, experimental results, measurements, simulations, resulting observations fieldwork, questionnaire results, surveys, interview recordings.

One of the first international OA initiatives with major impact was promoted in 2001 by the Open Society Institute (OSI) in Budapest. This event brought together researchers, higher education and research institution leaders to discuss OA strategies. This meeting established the meaning and scope of OA, yielding one of the most important documents and initiatives spearheaded by the OA movement: the Budapest Open Access Initiative (BOAI). The defined strategies consider mainly journals and authors self-archives in OA repositories [16, 17, 18]. The Berlin Declaration, signed by representatives of several scientific institutions, was an important step in the realization of the OA movement strategy as it defines OA and encourages researchers and grant holders of scientific institutions to publish their works in accordance with the principles of OA [19, 20]. The action plan adopted by the world leaders of United Nations state members in the World Summit on the Information Society (WSIS), lay the foundations for an information society for all, reinforcing the importance of OA [21].

2.1.1 Publications and repositories

OA considers two types of documents: the final version of journal articles after peer reviewing (postprints) and unreviewed versions (preprints), in case of preliminary reports of new results. BOAI has defined two major pathways of OA: green OA proposes that authors through self-archiving deposit their publications in an OA repository, even if the article is published in a scientific journal; golden OA corresponds to the publication of OA scientific journals exempt from subscription or fees restricting the access to the published articles. These OA scientific journals present some similarities compared to traditional scientific journals, namely peer reviewing, editing and publication, differing in terms of access level, as signatures or other charges are not required.

At present, according to the Directory of Open Access Repositories (OpenDOAR), several types of repositories have been implemented: institutional; governmental; and thematic, adding up to 5690 repositories worldwide [22]. Figure 1 illustrates the global landscape of OA repositories by country. As shown, the ranking is led by the United States of America (USA) with 907 repositories, followed by Japan with 683 and United Kingdom with 315 repositories. Regarding the African continent, with a total of 193 repositories, South Africa is the forefront country with a total of 44 OA repositories, followed by Kenya with 43 repositories and Nigeria with 30 repositories.

Regarding the implementation of repositories, there are several open source tools available, being EPrints and DSpace the most used. Currently, DSpace [23] has been the choice for implementing most repositories, about 39% compared to 11% from EPrints [24]. One of the main advantages of DSpace is its simplicity, being able to run from simple to more sophisticated machines, as long as the server is capable

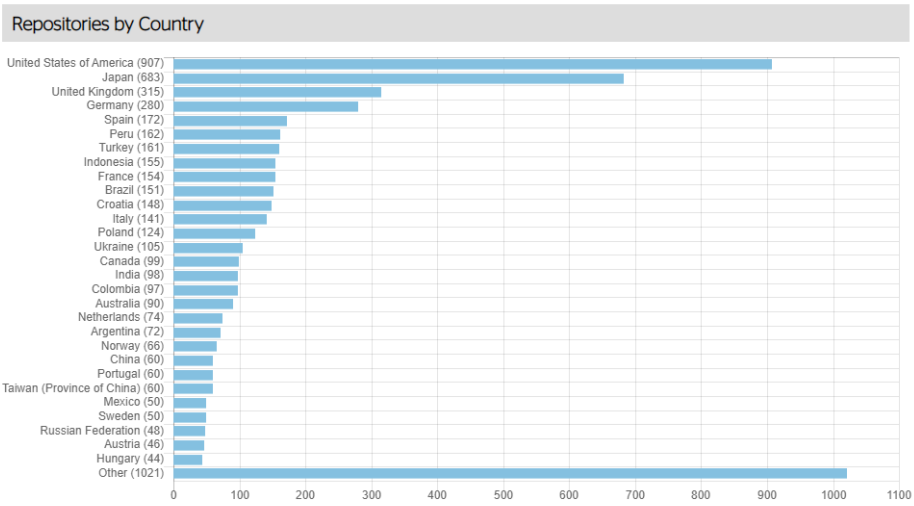


Figure 1: Repositories by country in the world [22]

of storing and processing data. The reduced cost of equipment is an advantage especially for institutions with limited financial resources and developing countries.

The initiative led by the Open Archives Initiative (OAI) in 1999, allowed to answer the need for interoperability between repositories and research of scientific publications in various areas, through the creation of a protocol for collecting metadata records in repositories, the OAI Protocol for Metadata Harvesting (OAI-PMH) [25]. In this context, OA represents a joint effort bringing the following benefits to researchers:

- increases the visibility and use of research results;
- improves the balance in accessing information (access to everyone: researchers, teachers, students, institutions);
- increases visibility to authors, and the valuation of intellectual property;
- improves the production of new knowledge, promoting the use and transformation of already existent knowledge;
- fosters interdisciplinary research.

2.1.2 Workflows

The process of submitting a document in a repository undergoes different checking stages, depending on the strategy adopted by each institution. Documents may need further revision for various reasons, such as improving metadata or complying with standards or criteria established by the hosting institution or community (e.g. blackout periods).

In this context, DSpace allows the definition of workflows for self-archiving, being defined the players in the distinct phases of the self-archiving process (depositors, reviewers, metadata editors), depending on the institutions' policies, and on the access control rules to limit access to documents for which restrictions have been imposed. DSpace also allows to organize the repository into communities and collections, corresponding to the organic institution units (e.g., schools, institutes, research centers, departments, faculties). Each community can be associated with various types of documents (e.g., doctoral theses, scientific articles, conference proceedings) and each typology represents a collection. Figure 2 illustrates the process of submission and acceptance of a document before being available in the institutional repository. This process may include three intermediate steps or simply proceed to self-archiving. In the simplest approach, the process may only involve metadata editing, and in the more complex case, peer approval, metadata editing, and final approval by a coordinator.

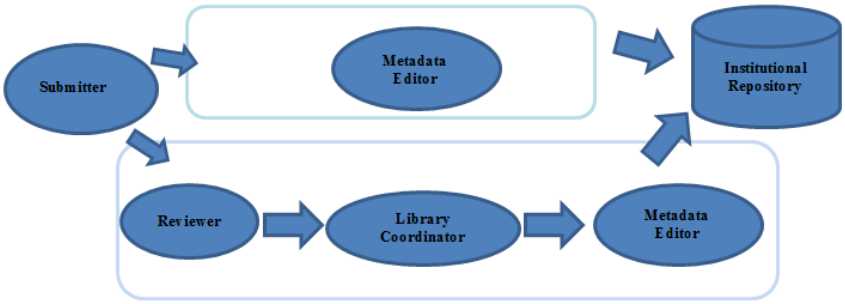


Figure 2: Autoarchive workflow

2.2 Open Access policies

As result of OA movement, national and institutional self-archiving policies have been adopted, particularly in Europe and the United States, as a way to encourage OA. Self-archiving means that authors deposit their scientific production in platforms or repositories, which will make them available publicly through the Internet. However, due to imposed restrictions, this process may incur a 6 to 12-month latency, within which the documents are not available. In the case of research and education institutions, one of the easiest ways of self-archiving has been through OA repositories.

To encourage the practice of self-archiving, it is essential to define OA policies on two fronts: institutional and national levels. Different governments aim to break the monopoly of commercial scientific publishers, especially as regards scientific publications resulting from public funds.

In 2004, 34 countries of the Organization for Economic Co-operation and Development (OECD) adopted a Declaration on Access to Research Data From Public Funding, recognizing that OA allows to leverage the

value coming from public investments in data collection, and that the risk of unauthorized access and use of data for scientific research restrictions can decrease the quality and efficiency of research and scientific innovation [26].

In 2007, the U.S. government took actions regarding the OA policy, resulting in a change in the biomedical and life sciences, with the adoption of a specific law for the National Institutes of Health (NIH), which requires all researchers funded by this institution to deposit their articles published in scientific journals in the PubMed Central repository. In early 2013, the U.S. government extended the action taken by NIH to all institutions in the country.

The established Office of Science and Technology Policy (OSTP) directives have been showing positive results. Data and publications resulting from government-funded research are increasingly available in OA, due to the statutes and action plans established subsequently, in June 2013, namely the Open Data Statute and the US Open Data Action Plan [27], launched in 2014. These initiatives have also been joined by the research funding agencies from the private sector, with some success stories of the following foundations: Ford; Alfred P. Sloan; and Bill and Melinda Gates, who also decided that the results of the research projects funded by their projects should be available in OA and reusable, but with some restrictions, depending on the sharing policies defined by the entities involved [28, 29, 30]. These actions represent the conscience of the U.S. government about the benefits of OA, to guarantee access to a wider range of scientific information.

The European Union (EU), following the strategies pursued by U.S., has developed several projects under the Seventh Framework Programme (FP7) for the period 2007-2013, highlighting the Open Access Infrastructure for Research in Europe (OpenAIRE) and Mediterranean Open Access Network (MedOAnet) for Mediterranean countries that are supported by the European Commission (EC) [31].

The OpenAIRE project, funded by the EU, is a portal that allows access to scientific content from 27 member countries. In this context, OpenAIRE is a consortium represented by southern European countries, including Portugal, Spain, Italy, Greece, Cyprus and Malta. The pilot project OpenAIRE (2009-2011) was refinanced for the period 2012-2014 and extended through new funding for the period 2015-2018, the latter being included in the current European Project Horizon 2020. This project includes research results covering 7 areas of study: health, energy, environment, social and human sciences, information and communication technology, research infrastructures and socio-economic sciences. Portugal is represented by the University of Minho (UM), through their library (*Serviços de Documentação da Universidade do Minho* - SDUM), and this choice is due to the fact that UM is a national reference for the creation of the first OA Repository (RepositóriUM) and its self-archive policy [32, 33].

The Zenodo project, within the OpenAIRE framework, is a multidisciplinary repository of research data

and scientific publications, focused on projects and institutions that do not have an institutional or thematic repository in compliance with the sharing and dissemination of research results from these institutions. Therefore, researchers are advised to choose alternative repositories that are registered in technological platforms such OpenDOAR, and Registry of Open Access Repositories (ROAR) [34].

With regard to the MeDOANet project, also funded by the 7th Framework Program of the EC for the period 2011-2013, it aims to reinforce policy aspects and strategies related to the OA issue, such as improving policies and strategies and existing OA structures, and to create new ones, by identifying and mapping them, at national and regional level in 6 Mediterranean countries, namely: Greece; Turkey; Italy; France; Spain; and Portugal. It is a consortium made up of 9 partners from Mediterranean and northern European countries, which involves political decision-makers and other stakeholders in the area of OA, with the aim of promoting the change and awareness of relevant issues that require the capacity to act [35].

2.2.1 From the Horizon 2020 to Horizon Europe

Horizon 2020, covering the period 2014-2020, was defined as the largest innovation and research program of the EU, whose objective is to foster the growth of scientific breakthroughs, the transfer of innovative ideas and scientific results from laboratories to the Marketplace. The EU has decided to invest almost €80 million in the public and private sectors, focusing on three key points: scientific excellence; industrial leadership; and societal challenges, for the future of Europe. Thus, as a way of sustaining economic growth, the aim is to ensure that EU member countries can produce cutting-edge science and technology worldwide [36].

In terms of OA, Horizon 2020 reinforces the recommendations previously defined, extending them to the availability of data, in addition to scientific literature in OA. In more detail, the new guidelines of OA launched under Horizon 2020 [37], cover the following key points for researchers:

- *licenses*: encourage authors to retain the copyright and to agree with editors on the appropriate use of licenses, such as creative commons;
- *data*: data resulting from research, including the associated metadata necessary to confirm the results, must be deposited in a scientific data repository;
- *metadata*: free access to bibliographic metadata related to the deposited publication must also be provided (the terms of the funder, the action's name, the initials and number of the agreement, the publication date, the embargo period and a persistent identifier);

- *costs*: eligibility of costs of OA publishing during the project should be identified, especially in cases where the researcher has to pay an amount to publishers to have the publication in OA.

The Horizon Europe program, the successor of Horizon 2020, covering the period between 2021-2027, includes an ambitious research and innovation program budgeted at €100 billion proposed by the EC as a guarantee for its success. In this sense, five mission areas were identified as strategic, namely: Adaptation to climate change, including social transformation; Cancer; Climate neutral and smart cities; Healthy oceans, seas, coastal, and inland waters; Soil health and food. In this context, in addition to the introduction of new strategies, open science will continue to be part of Horizon Europe focus and will go beyond the Horizon 2020 OA policy, in which OA to scientific publications and data, and research data management plans will be required [38, 31].

Note that, under Horizon 2020, while OA for scientific publications involving peer review was a well-established requirement, OA for research data on existing projects was in a pilot phase, being enforced by the EC. Under Horizon Europe, it is expected a broad adoption of the directives established for research data. This aspect will be discussed in more detail in Section 2.3.

2.2.2 Dissemination and Data Management Plan

One of the first criteria established by Horizon 2020 is the choice of an appropriate action plan for dissemination and sharing of the results of research projects in question, which demonstrates that it contributes to the growth of science.

A proper dissemination plan should be simple and focused on the following aspects: it requires an identification of interested stakeholders and strategic areas that will take advantage of the project results; it is necessary to establish concrete and coherent dissemination actions throughout the life cycle of the project. Typically these aspects are under the responsibility of the project manager, which should involve the selection of channels and dissemination platforms, such as project sites and implemented policies [37].

Figure 3 provides a global view of the decision process regarding the results of a research project, involving: i) the dissemination/share decisions; and ii) the exploit/protection of intellectual property, through patents or other protection strategy. In the dissemination process, publications and data will be made available in free or restricted access. Community directives point out to the sharing and dissemination, and to free access to data and intellectual property.

With respect to Data Management Plan (DMP) issues, a key element is what characterizes a data life cycle since its collection, processing and/or generation from a publicly funded project. A DMP should also

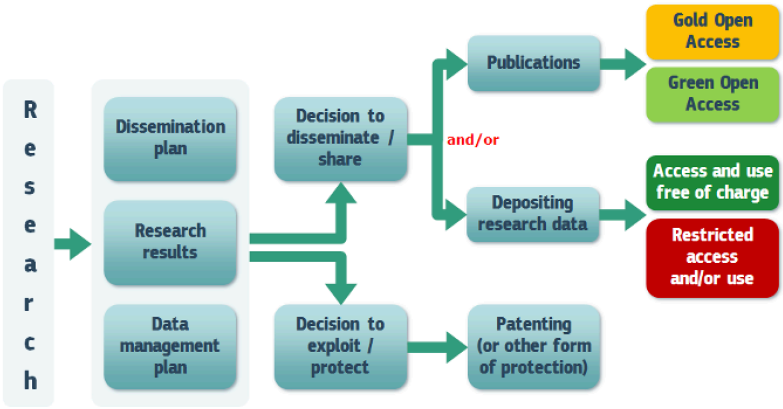


Figure 3: Open access decision process [37]

be considered as a preponderant part of a proposal for funding a research project. For this, it is important that such data are available, easy to locate, accessible, interoperable and reusable (FAIR: Findable, Accessible, Interoperable and Re-usable). In this context, the treatment of data (data curation) should be considered throughout the entire research cycle until the project ends, which involves the choice of data, the methodology used and the standards applied to answer the research questions. It is relevant to take into account that the data must be analyzed and interpreted in an appropriate way, so that it can be converted into results and conclusions of a research project. There is also the question of deciding how these results will be shared, more specifically, publications in gold or green open access; research data to be used free of charge or restricted access; or to exploit or protect of research results using patenting or other forms of protection [37].

When the project has been completed, there are usually two ways of using the results, either by public and/or private companies for commercialization, or as a means of defining or formulating strategies and/or public policies. To this end, the EU has created a variety of services to support researchers in dissemination and exploitation activities.

An appropriate exploitation and dissemination plan should be prepared with care, as there is no single template to follow, unless the project call includes one, yet it should be as accurate as possible and updated throughout at the end of the project. Such plans should also seek to answer the following questions:

- In which areas should the project have the greatest impact?
- What solutions can project outcomes help to solve?
- Who are the possible users of the results?
- How to reach/communicate with potential target users?

- Where will the results be made available during and at the end of the project?

2.2.3 Intellectual Property challenges

As illustrated in Figure 3, the decision to protect research results is also a concern of the OA decision process, framed by Intellectual Property rights.

The Human mind has the ability to think, to be creative and to develop knowledge for the benefit of humanity. In this sense, Intellectual Property is related to the use of mind support to create, for instance, inventions, literary works, drawings, images, and names which are mainly used in commerce. Intellectual Property protection ensures that a company or individual stands out in the market and, in this case, two categories should be considered, Industrial Property and Copyright [39, 40], as follows:

- *Industrial Property*: which is concerned with aspects related to the industrial sector, such as patents resulting from inventions, trademarks, geographical indications related to the origin of goods (mainly agricultural), and even industrial designs.

- *Copyright*: which is, in most cases, related to the protection of literary works (may come in the form of poetry, novels, articles, children's stories, etc), works of art (films, computer programs, paintings, sculptures) and architectural projects.

Intellectual Property rights exist as a way of protecting patent owners or inventors so that they can benefit from the effort made in their work and from the investment outcome resulting from an invention. As they are embodied in Article 27 of the Universal Declaration of Human Rights of 1948:*"1.) Everyone has the right freely to participate in the cultural life of the community, to enjoy the arts and to share in scientific advancement and its benefits. 2.) Everyone has the right to the protection of the moral and material interests connected with any scientific, literary or artistic production of his own".* [41].

The promotion and intellectual property protection are factors that enable the development of human creativity to invent and produce new scientific, technological and cultural knowledge, which favors the development and improvement of the living conditions of humanity. In this context, it is also important to emphasize that new creations are supported by new resources that enable innovation to grow. It is also necessary to promote Intellectual Property protection as an incentive to create jobs and industries that generate economic growth.

It is also recommended that the new technology be patented, otherwise, there is always a danger of being copied and the inventor caught unawares for not being legally protected. Nevertheless, there is a risk that another competing or less creative company may misappropriate this new creation and the real

author may be prevented from using it. In such cases, any lawsuit that the inventor attempts to bring will be almost impossible to win.

Clarifying Intellectual Property taxonomy

Regarding the framing of patents and Intellectual Property taxonomy, which is often confused or misinterpreted, in more detail:

Patent: within the scope of industrial property, an invention must be protected, in this case a patent is the form used, being an official title guaranteeing the exclusive and temporary use of the invention. Such protection is given for a restricted period, usually 20 years, ensuring that the invention can only be produced, marketed or used only with the permission of the patent owner. Thus, when the patent protection period expires, the invention enters into the public domain, and patent holders are required to publicly provide information about their inventions. In the case of large companies, they usually invest in obtaining a patent portfolio as a way to value the company and get a higher return on their investment in inventions. Patents are, therefore, one of the aspects that indicate the technical superiority of a company. In the event of insolvency or closure of its business, the company's patents are considered to be a property and may be traded jointly or separately [42, 43, 44].

Invention, Innovation and Discovery: In addition, care must be taken to distinguish between invention, innovation and discovery. In this context: *Invention*: is the creation of something new (technology, process, object or system of relationships, or even the improvement of existing creations), whose purpose is to give answers to a particular problem. As a result, an invention must demonstrate some novelty that could not be created by someone with average knowledge in the area concerned; *Innovation:* is largely related to industry and scientific research, and it concerns the practical utility of the invention, aiming to respond to market needs, thus becoming a marketable product; *Discovery:* is related to obtaining a new knowledge, which is usually acquired by chance or without any effort.

Discoveries can lead to inventions. However, when trying to compare discovery with invention, it is necessary to address issues related to science and technology, and realize that many scientific discoveries depend on technologies. For example, Benjamin Franklin made discoveries about electricity that allowed him to later invent the lightning rod [45].

Cooperation between industry and academy

Teaching and research are the main functions carried out at Higher Education Institutions (HEIs). The last is responsible for the knowledge production that can be accessed through OA. Nowadays, with the

advance of directives applied to OA, scientific research carried out at universities also responds, directly or indirectly, to the demands of commercial entities. In this sense, there is an understanding that a large part of scientific research is carried out in universities, and open science enforces the publishing and access to research results openly.

In HEIs, it is required a continuous production of scientific contributions, considered crucial for the reputation and recognition of the institutions and research centers. However, an aspect that generates some controversy, is related to the protection and appropriation of knowledge acquired with the intention of commercial return, which can go against the principles that support open science. In fact, several studies reveal that this aspect, related to Intellectual Property, can negatively influence the freedom to share knowledge and ideas needed to solve real problems. This focus on commercial advantage end up questioning the OA to knowledge and results in the development of research.

Regarding the confidentiality of scientific production carried out in universities in terms of patents belonging to researchers associated with research centers, this framing can lead to a reduction in the sharing of knowledge between researchers in the public and private sectors. This also ends up generating some rivalry within universities regarding financial resources from the same commercial relationship, and negatively influences the norms of university culture in the context of open science. In practice, "rivalry" can affect relations between universities and the commercial sector instead of bringing gains for both parties [46, 47].

2.3 Open Data movement and directives

The Open Research Data movement recommends that scientific data should be publicly available for free, without copyright restrictions, patents or other control mechanisms. Despite being related to other open movements in science and society, such as the Open Source and Open Access, the Open Research Data movement has its own aim, dynamics and agenda, being gaining the support of the scientific community which is multiplying the initiatives, projects and statements on the topic. The scientific community is presently more aware of the explosion of scientific data production, as result of the global growth of research activities and of new methods and tools for data search and registration, which originate increasing data volumes. Therefore, in addition to the production, collection, analysis and interpretation of scientific data, the main focus of researchers' work, they have now to consider another area of intervention, related to the curation of scientific data. This implies managing the access and use of collected and/or produced data in research activities, ensuring their preservation and sharing [26].

With regard to policy makers, a vast number of initiatives and declarations have been launched both at Portugal level, in the European context and by international associations. One of the first and most relevant signs of the importance of open access to research data was the Declaration on Access to Research Data from Public Funding, approved by ministerial representatives of 34 countries (including Portugal) under the OECD, in 2004 [26]. This declaration promotes scientific progress and values the return on public investment in data activities. It states that undue restrictions on access and use of data can decrease the quality and efficiency of scientific research and innovation, and declares the willingness to work for the establishment of regimes of access to qualified public funding data. As a result of this declaration, the OECD approved in 2006 a document of Principles and Guidelines for Access to Research Data from Public Funding, published in 2007 [26].

In this context, the OECD defines research data, as *"Factual records (numerical scores, textual records, images and sounds) used as primary sources for scientific research and that are commonly accepted, in the scientific community, as necessary to validate research findings. A research data set constitutes a systematic, partial representation of the subject being investigated."* [26]. This is the definition most often used for research or scientific data.

According to the European Commission, Open Research Data refers to the data underpinning scientific research results that has no restrictions on its access, enabling anyone to access it. The indicators chosen are: availability of data repositories; policies of research funders and journals; and researchers' attitudes towards data sharing [31].

According to United Nations Educational, Scientific and Cultural Organization (UNESCO) and Johnston [28, 48], scientific data refer to literary, artistic or scientific creations, which can be divided into 5 types, as shown in Figure 4 and described below:

- *Data sets:* relevant for the analysis of large volumes of data, which result from direct observations by the researcher, computational or database that depend on specific software, simulated data or otherwise. In order to be properly analyzed, the data sets must have a square or rectangular format where the lines represent the records of the events and the columns the characteristics of the same.

- *Digital collection:*encompasses all types of grouped digital objects such as book libraries, and archives of different types: photographic; cinematographic; audiovisual works; musical compositions with or without lyrics; drawings of architectural and engineering works; among others.

- *Learning objects:* characterized by the distribution of learning content in digital format.

- *Multimedia:* include recordings of films, music, theater, dance and other performance arts, framed

in the area of animation, in order to introduce greater creativity in the pieces produced by the producers of audiovisual recordings, phonograms, radio broadcasting entities, artists and interpreters.

- *Software:* computer programs (open source software) including files with lines of code and associated documentation.

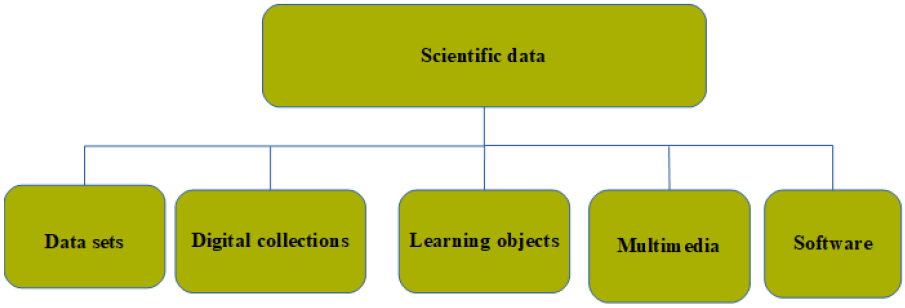


Figure 4: Scientific data

As mentioned, changes have also taken place in the way scientific data are stored, preserved and shared. In many areas of science, modern research has the challenge of dealing with large volumes of data, especially in genetics, medicine, meteorology or physics. Thus, Open Research Data requires technological infrastructures with computational capacity that allows organizing this level of data in public or private databases, and with the ability to retrieve, recombine and process, so that they can finally be accessed and reused. In this context, data collection, curation and analysis are the three important activities of this new type of science, today called data-intensive science [49, 50].

Intellectual Property and copyright are considered factors limiting the implementation of Open Research Data or the reuse of scientific data, previously mentioned, which led to the open science advocacy movement. One of the greatest examples of major visibility is the ambitious Human Genome Project (HGP). Mostly funded by public funds, HGP began in 1990, resulting from an international consortium and involving research programs in 18 countries of all continents, except Africa. Some developing countries had their secondary collaboration through technical studies focusing on their geographical regions [51]. During the 13 years of the project, there was a real threat that HGP data would not be made available in the public domain, due to a patent application filed by Celera Genomics, a private company that was involved in the project. In 2000, a biology doctoral student set up a GigAssembler-based program that went against the intentions of the private company, and HGP data was made available in OA [52].

2.3.1 From storage to curation

Data storage and curation are distinct, although interrelated, concepts very relevant in the context of Open Research Data.

Data storage

The current scenario of ICT brings several challenges, thanks to new fixed and mobile devices, which allow connectivity in a ubiquitous way and the evolution of technologies and network infrastructures. This is a fact that drives the creation of new services and applications, such as voice over IP (VoIP), video conferencing, online games, web services, multimedia applications, social networks, etc, which corresponds to an inevitable exponential growth in the volume of data available on the Internet.

Taking into account the aforementioned facts, data storage requires the use of data transfer resources that will allow the preservation and protection of data in a safe environment. Usually, this requires selecting the relevant data, collected in the small magnetic or optical devices used by the researchers through the years (for example, cassette, floppy disk drive, Compact Disc (CD), Digital Video Disc (DVD) and, more currently, pen drives). This process, may take years to be accomplished.

In a distinct dimension, storage devices and technologies that involve gigantic data volumes, for instance resulting from international projects, imply the use of other types of network mechanisms and infrastructures to allow data transfer to devices with proper capacity to store data. As example, projects in the domain of astronomy and particle physics, such as the data produced by the Large Hadron Collider (LHC) project, from the European Organization for Nuclear Research (CERN) [53, 54, 55], which can generate several dozen petabytes per day, presents distinct storage challenges.

In the latter case, the use of dispersed data centers is usually required, located in several geographic regions as a way to guarantee the replication of data among themselves (redundancy). At this level, the computing infrastructure aims to allow all institutes and employees to actively participate in data analysis and in simulation activities, that are also substantially demanding [56].

Data curation

Data curation consists of maintaining, preserving and adding value to existing data throughout its entire life cycle. There is an enormous difficulty in preserving the data so that can be reused by third parties (future generations) and enable more research based on it, due to its variety and complexity. That is why it is essential to evaluate the different digital objects and select those that must be preserved and maintained,

that is, to create and manage quality data. In this way, reducing duplication of effort, and costs of creating and transferring data are essential aspects of data curation. Another aspect of curation is that it reduces threats to its long-term research value and mitigates the risk of digital obsolescence (obsolete, outdated, or falling into disuse) through active data management.

In this context, after collecting data from different storage devices, the methodologies used in data curation involve two main processes, namely archiving and preservation, these being continuous, using other methodologies that allow to create and manage quality data and with the capacity to add value to them, generating new sources of information and knowledge.

In summary, data curation does not end clearly with the creation of metadata and involves the set of actions that guarantee the authenticity, integrity and accessibility of scientific data. In this sense, data curation involves all the necessary preservation activities to guarantee the possibility of being used again in the future.

2.3.2 Data repositories

Data repositories are large database infrastructures defined for managing, sharing, accessing and archiving researchers' data sets.

Data repositories can aggregate data from experts globally or locally, collecting data from researchers at a university or consortium of universities for mutual benefit. This sharing of data improves results and drives research and discovery. In fact, when the data resulting from the research is brought online, it allows quick access to a globally dispersed group of researchers to share, understand and synthesize the results. Even previously hidden data resulting from experiments that did not work can be published in the data repositories. This allows other researchers to avoid going through the same situation and find better solutions.

Data repositories allow long-term archiving and preservation of data in different formats, including simple Excel, Statistical Package for the Social Sciences (SPSS) or Geographic Information System (GIS) form files, and specific Genome data formats. Usually, a repository also provides a permalink strategy (permanent link) for online citation and instant access, so that researchers can offer a direct link to their data and auxiliary files in the article or conference article published later. In this case, it is usually provided a Digital Object Identifier (DOI) or Universal Numerical Fingerprint (UNF) that allows later linking of the data and enables interoperability and merging of data files.

In the United States, any researcher who wishes to receive grants from any public agency is obliged to place research data in a repository, that is, the data resulting from research carried out with public funds.

This includes the NIH, National Science Foundation (NSF), U.S. Department of Agriculture (USDA), and National Endowment for the Humanities (NEH). For that, it is necessary for the researcher to have a DMP, since the data sharing helps to keep the economy in general vital, facilitating healthy competition towards the commercialization and dissemination of discoveries [57].

In Portugal, until the end of 2009, the activities of the RCAAP project were more directed towards the repositories of scientific literature. However, in 2010, the pilot project to implement a research data repository focused on the access and curation of research data was launched. The initiative to create a pilot project on research data demonstrates the recognition of the growing importance of questions related to data from research activities in the scientific communication system and in the global functioning of science.

Going further in this context, Zenodo is a generalist repository, associated with the OpenAIRE project that ensures the storage capacity and digital preservation of the deposited data. Dryad is a repository of scientific research data, always subject to a curatorial process. Dryad is integrated with several scientific journals, fulfilling their requirements regarding the joint submission of research data and facilitating the peer review process. Data deposit has an associated cost, depending on the financial model and the journal associated with the publication. Figshare is a generalist repository, part of the Digital Science business group, a Macmillan Publishers group company. Figshare is an online repository where research institutes and researchers can preserve and publish all types of content resulting from the research process. Its use is free of charge and the data deposit is entirely the responsibility of the user. This repository is integrated with several scientific journals, which increases its visibility.

With regard to the software used to implement research data repositories, Dataverse, HUBzero, and Chronopolis were created specifically for this purpose. DSpace, Fedora, and Hydra are text-based institutional repository or digital library sources.

2.4 Research Information Systems and OA

Technological platforms and infrastructures for managing science have been under debate worldwide, being well-grounded and widely deployed concepts in developed countries. Although the emerging interest of developing countries in these topics is evident, much work has to be done to promote national scientific production and the availability of scientific content without restrictions. As a vehicle for knowledge sharing, NRENs play a key role in science growth and OA deployment. In addition, the CRIS has emerged as an embracing paradigm for managing the multitude of science components and players. Instantiating these

concepts and directives in the science ecosystems of developing countries will save years of progress, bringing these countries directly into a high-level regarding science management.

2.4.1 CRIS

The CRIS concept arises as an information system that stores data on research carried out by organizations and researchers, usually related to projects under funding programs. CRIS can manage all relevant information directly related to research, starting with funding opportunities, through calls and proposals, following the publication of winning proposals that will become active projects to be managed and monitored until completion. Such projects generate outcomes, resulting in scientific publications or other types of documents or products [58, 15]. Managing science based on CRIS can bring the following benefits:

- offer to administrators and science managers tools that facilitate the evaluation and report of scientific practice;
- offer to researchers and academic community tools for accessing and managing information about scientific activity;
- facilitates media professionals, technology transfer companies, civil society organizations and individual citizens the discovery of innovative technologies and ideas, promoting links between science and society.

In this sense, CRIS will provide information on publications resulting from research produced in an institution, and corresponding authors. More information can be obtained, such as the activities, projects, departments, funds and portals that can provide information to researchers in order to increase the visibility of research results produced in the involved institutions. In more detail, CRIS components are represented in Figure 5 [59].

- Academic expertise: platform for collection, delivery and analysis of intellectual production, scientific and other curriculum information from national researchers, which should be promoted by the government entity that manages science. As examples, the Lattes Platform in Brazil and DeGois in Portugal can be cited;
- Organizations database: database of research and development projects approved through competitions annually open to all scientific areas or through calls targeting research in certain areas or specific topics;

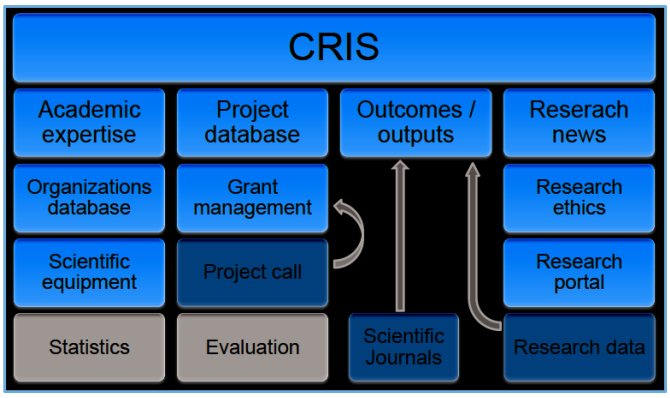


Figure 5: CRIS Ecosystem [59]

- Scientific equipment: database of research infrastructures and equipment, especially research infrastructures of strategic interest for supporting scientific and technological advances, and for enhancing the development and innovation capacity of the research community;
- *Statistics*: science indicators;
- Project database: database of Research and Development projects; the portal allows to see the list of approved projects through competitions;
- Grant management: portal for submission of applications for individual grants, after registration in the Information System;
- *Projects call*: portal for submission of applications for Research and Development projects, after registration in the Information System;
- *Evaluation*: evaluation of research quality;
- Outcomes/Outputs: corresponds to the creation of technological platforms, specifically OA repositories that allow the deposit, access and sharing of knowledge of national scientific production results, publicly funded by policies and governmental/institutional mandates;
- *Scientific journals*: another way of publication of scientific production in OA is carried out through OA scientific journals, i.e., Gold OA;
- Research news: management system of news related to investigation;
- Research ethics: database with information on ethics in science;
- Research portal: integrated search system;

- *Research Data*: the data used in research must be deposited in a data repository.

2.4.2 New trends for CRIS

Currently, the EU has been a major engine of the debate on the development, integration and interoperability of services and platforms for managing science.

As mentioned, one of the European initiatives related to OA is the OpenAIRE project, which is an integral infrastructure that allows to manage scientific publications, and the information associated with them, through a network of repositories. This project presents several advantages because it links the aggregated publications in the repositories with financing information and scientific datasets [33]. To be more effective, the project also provides a service help-desk and technical guidance to all partners involved.

In a regional panorama, projects such as OpenAIRE can benefit:

- researchers in the deposit and sharing of research results;
- national OA initiatives to establish, implement and align scientific data policies;
- repository managers to increase the visibility of content;
- policy makers and funders to monitor the results of funded research;
- managers of projects and science administrators to support the realization of reports, statistics and dissemination of research results;
- potential data providers wishing to explore the interconnection of their research.

EuroCris and CERIF model

In the European context, the euroCRIS is a non-profit association that brings together professionals of research information and of CRIS area for *"development and curation of the international standard data model for research information called CERIF: the Common European Research Information Format. The promotion of cooperation and exchange of expertise between stakeholders in the research information domain ..."* [60]. In this perspective, the euroCRIS has developed CERIF, which is the standard model of storage and interoperability of research information, e.g., the research metadata. CERIF has the advantage of including all components of research information of CRIS and the ability to represent the relationships between entities that are semantically defined [15, 61]. The CERIF-XML is a language that allows the

exchange of information between systems.The CERIF/CERIF-XML are recommendations to EU member states.

The CERIF model, illustrated in Figure 6 [15] , provides a large flexibility and robustness because complex roles and date-limited relationships between the three major entities (in orange) can be expressed, and other entities can be linked by role/date relationships to any or all of these three major entities. As example, it is possible to convey information such as: "How many PhD students took part in national research projects?"; "In which countries did they obtain their master's degree?"; "How many scientific papers have been published by author R in 2016, being R the first author?" [7, 3].

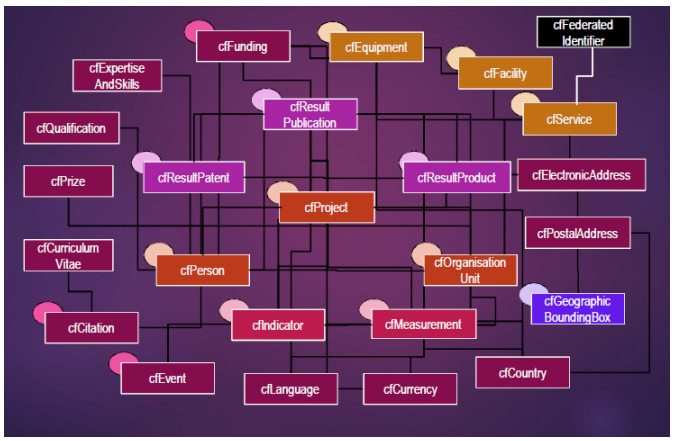


Figure 6: The CERIF model [15]

ORCID

To avoid ambiguity in the use of authors' names and to automate links to research, the Open Researcher and Contributor ID (ORCID) organization, an international, non-profit organization, governed by the research community, has as main activity to provide the registration of open unique identifiers for the researchers and academic community [62]. The unique identifier ORCID iD allows identifying unequivocally each researcher [63, 62, 64] and facilitates the recovery of his scientific production linked to other existing systems of authors identification, such as ResearcherID, Scopus Author Identifier, My Citations Google Scholar, etc. In the case of EU countries, the use of ORCID iDs will allow:

- to implement a national repository, solving problems in communication and interoperability of national and institutional information systems;
- to integrate efficiently in national reporting systems researchers from foreign institutions who come to develop their activity, and allow national researchers to export easily their scientific production to the information systems out of the country;

- to obtain an ORCID iD is free and simplifies bureaucratic processes, allowing the use of only one record to identify a researcher into multiple entities.

The use of ORCID iD identifiers is already being adopted in the science management systems of various countries, editorial groups (e.g., Nature Publishing Group) and funding agencies (e.g., NIH and FCT in Portugal), who seek to follow recent directives on CRIS and OA. In this sense, it is important that developing countries or institutions with limited financial resources rethink existing open source alternatives to create repositories and forms of integration and interoperability with existing CRIS systems.

Regarding CRIS evolution, the study conducted by [65] reports that one of the biggest challenges encountered is related to the coexistence of CRIS and repositories, since they have distinct concepts, however, the trend is the integration of these two systems, for their coexistence in future. Another important aspect to be considered is that, while the platforms for building repositories are open source platforms such as Dspace and ePrint, the main existing CRIS platforms are all based on proprietary systems. Nevertheless, there are CRIS open source development projects, but it is still premature to say whether they will be accepted by the community.

Taking into account the perspective presented on the new CRIS paradigm, at present, this trend of change appears to be more at the European level, although it corresponds to more advanced systems for managing science [65]. In this sense, it is important that developing countries or institutions with limited financial resources rethink existing open source alternatives to create repositories and forms of integration and interoperability with existing CRIS systems. At the interoperability level, the main CRIS data collectors are Academic expertise, Research portal, Outputs and Project database. The main data providers are at Organization database and Output levels.

2.5 Summary

In this chapter, the main open science concepts have been introduced. In particular, Open Access and Open Research Data movements have been debated and their main initiatives, directives and policies reviewed. The discussion was also focused on the relevance of comprehensive science management IS, for managing the myriad of science components and players, fostering knowledge development and data interoperability. The following chapter will concentrate on the role of technological infrastructures in sustaining the mentioned open science concepts, and the teaching and learning frameworks.

Chapter 3

Technological Infrastructures Supporting Science and Education

National Research and Education Networks (NRENs) organizations emerged over the last 25 years from the need of the research and education community to address technical, financial and administrative issues arising from a rapidly evolving networking environment. Nowadays, NRENs represent important vehicles for sharing knowledge among educational and research institutions, linking them to provide high-speed networks and advanced services that foster the development of science in countries [66, 67]. Apart from Internet access and other services provided by NRENs, a major concern of the scientific and academic community is access to information, and developing strategies for sharing knowledge is viewed as a major issue for the progress of societies. As mentioned before, one of the major impairments in the access to scientific information is that the full contents are not always freely available. Particularly in developing countries, this problem is stressed by the lack of consistent network infrastructures to support information sharing and financial resources to access scientific content.

In this context, having highlighted the importance of OA in the previous chapter, this chapter debates the NRENs concept and the need for a joint involvement between governments and local NRENs in order to ensure that NRENs are incorporated into the national system of science, technology and innovation, and serve the needs of the research and education community. In addition, as relevant education models supported by NRENs in developing countries, e-learning and podcast are debated.

3.1 NREN concept and components

NRENs aim to connect higher education institutions and research centers through advanced communications infrastructures, providing services to its community in a different model than using commercial Internet Service Providers (ISPs). In addition to Internet services, that allow research collaboration and

knowledge sharing, other services such as housing, distributed computing, webconferencing and scientific repositories can be provided.

The European continent is recognized as the major driver of the NRENs concept, becoming a world leader in this field. The vast majority of European NRENs have similar characteristics, such as being supported by non-profit organizations and providing advanced services to the community. In this context, in Europe, GÉANT network is a partnership between different NRENs that has been growing in involved partners, allowing it to become more comprehensive at a global scale. This expansion, involving links with other continents, enables the creation of a global network, promoting the collaboration between the European academic community and academic communities located in other regions of the world [66].

Following the success of existing NRENs in Europe, Asia and North America, this model has gained recognition and there are currently NREN projects in more than 100 countries around the world, differentiating themselves in the business model, financing and provided services.

Regarding technological issues, to build an NREN it is essential to consider important aspects that depend on each country's reality, namely: the national backbone; the access network or last mile; and the international connectivity. These aspects are discussed in the following sections.

3.1.1 Backbone infrastructure

The backbone infrastructure may be the most cost element for an NREN and the deployment options vary. The report presented by [68] suggests the existence of the following initial investment options:

i) *purchasing bandwidth capacity*: this option presents lower costs at the start of the project when there are strict financial restrictions to move forward. However, in the long term, can prove to be disadvantageous as the volume of traffic increases and, therefore, the need for upgrading bandwidth arises with the corresponding costs depending on the market;

ii) *purchasing managed services*: this option is considered valid mainly for countries with a lack of qualified personnel to operate telecommunications links. In this case, the physical network is owned and operated by a national telecommunications company and NREN accesses are performed through a Virtual Private Network (VPN) from its own Network Operations Center (NOC);

iii) *leasing dark fiber*: this option proves to be the most sustainable in the long term, when the NREN community participates intensively in international partnerships. It also depends on the duration of the partnership project, as a high initial investment is required, but achieves lower operating costs for the capacity provided (dark fiber prices range from $5k to $20k per kilometer). The dark fiber is usually rented as an Indefeasible Right of Use (IRU) of 10 to 20 years, with annual maintenance calculated in

terms of miles of routes [69].

3.1.2 Access network or last mile

The need to connect individual campi to the NREN backbone typically uses Points of Presence (PoPs) located in the main cities where adherent institutions are located. PoPs may be located at the customers' premises or in the ISP contracted by the NREN. For universities outside urban centers, connectivity options depend on the fiber coverage in the country and whether universities are located in remote areas. In this case, it may be necessary for the NREN to build its own physical infrastructure from the backbone resorting, usually, to fiber optic cables or microwave connections. Depending on the policy, this task may be the responsibility of an individual institution, or part of the NREN portfolio [68].

3.1.3 International connectivity

The integration of the European continent through the GÉANT network is an example of successful implementation and management of an advanced network that presently interconnects all countries. For Asia-Pacific countries, Asia Pacific Advanced Network (APAN) is the international network that promotes the research and education in this region. In Latin America there is CLARA, the Latin American Cooperation of Advanced Networks and, in case of North America, Internet2 interconnects the American educational and research institutions. Considering this scenario, Internet Exchange Point (IXP) is a physical infrastructure through which ISPs exchange traffic between their networks (stand-alone systems), thus reducing the volume of IP traffic normally delivered using other autonomous systems. The exchange of traffic, by transit or by peering, are two scenarios normally considered by ISPs. The exchange of traffic by transit, i.e., when routing traffic from an ISP's network requires the use of one or more autonomous systems (national or international) usually has costs, which are charged per volume of transmitted traffic (Mbps). In a peering relationship, where IXPs are framed, agreements are established for the exchange of traffic between all ISPs that generally have no associated costs, sharing only IXP's operational costs. In addition to cost advantages, direct interconnection through an IXP guarantees high levels of connectivity, especially in two Quality of Service (QoS) metrics, latency and bandwidth, among others [70]. These aspects have contributed to the vital importance of IXPs in the Internet infrastructure, thus allowing the increase of online contents and local services, especially in developing countries where national services are limited and traffic generated by local users is mainly international, resulting in high financial costs [71]. At the global level, AMS-IX (Amsterdam), DE-CIX (Frankfurt), LINX (London), are considered three of the largest IXPs by associated traffic volume [72].

3.2 NRENs advanced services

As mentioned, NRENs provide high-speed network infrastructures and advanced services to educational and research institutions, enabling the developing, sharing and access to science. As illustrated in Figure 7, among the communities that can take advantage of NRENs support one can find HEIs, public libraries, museums, schools and some public and government entities. Services provided by NRENs span from Internet connectivity to application services, including all the necessary operational supporting services. Within the context of this work, scientific repositories and digital libraries are examples of Hosting and Data services. In particular, Connectivity, Application Services and Multimedia support the multitude of knowledge sharing, teaching and learning projects.

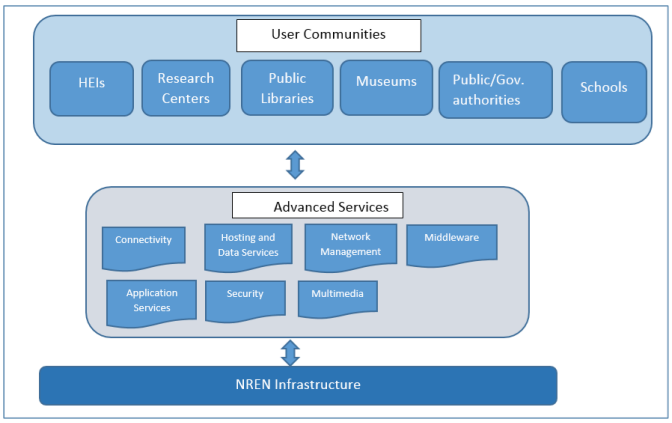


Figure 7: Organizational view of NRENs supporting science

NRENs are usually supported by non-profit organizations. Taking into account the existence of commercial ISPs, there are no conflicts of interest because, despite working in a similar way, ISPs operate at different levels, being not particularly oriented to respond to the requirements of the NRENs limited group of users.

3.2.1 Organization model

The creation of an organizational model for each NREN that attends to the reality of each country in coordination and collaboration at continental level, has been the key to the success of NRENs in Europe. Therefore, this model has been recognized and implemented in various regions of the world [66, 73]. In more detail, the European model considers three essential levels - local, national and international - which are described below:

- Local: corresponds to the networks of a NREN member. This level is linked directly to end users,

that is, the academic community (researchers, teachers, students, etc.) and it is the responsibility of managers and technicians of the local network to provide connectivity and services at the campus level.

- National: this level concerns the national interconnection of all member institutions in each country, being managed by the entity responsible for the NREN of the country.
- International: this level is related to the international connectivity among the NRENs of European countries and is provided by the GÉANT network. In this context, GÉANT is a partnership between the different NRENs partners [73, 74] which, through links to other continents, enables the creation of a global collaborative network for science growth.

The development of fiber-optic infrastructures came to boost research and innovation, as they enable to operate at much higher bandwidths, a factor that spurred the creation of new applications with large bandwidth requirements for data sharing between institutions. In addition, they allowed to conveniently assist distance learning projects, which proved to be particularly relevant in developing countries and effective in supporting teaching in critical situations, such as the COVID-19 pandemic lockdown.

3.2.2 Distance education: e-Learning and Podcast

The use of resources in digital format aims to improve the access to information, especially for users in remote locations, allowing the academic and scientific community to share information at any time and in any place [75]. In developing countries, where the access to information and the sharing of knowledge are still scarce, especially in rural areas, the use of supporting platforms for distance education is considered a key aspect to promote science and education. In this context, e-learning can be defined as a crucial teaching medium in which the access to ICT, such as the Internet and personal devices, is critical to support learning systems and applications.

Contents in audio-visual format have increased significantly in the last years due to the technological development at computational and telecommunications levels, supporting the production, consumption and knowledge sharing. The reduction of the cost of audio-visual equipment and telecommunications, along with the considerable knowledge of users in the areas of ICT, are factors that influenced this trend. With the advent of Web 2.0, the practices of production and availability of online content have been facilitated, being the creation, publication and distribution supported by several Web 2.0 platforms (wikis, blogs, podcasts, forums, YouTube, Vimeo, social networks, among others). This evolution allowed users to switch from simple consumers to producers of online content, fostering their use on a regular basis

in the context of teaching and learning, and providing an interactive environment that enables users to collaborate remotely and actively, creating contents, editing and sharing knowledge in audio or video format. This evolution brings advantages mainly in the student learning process, facilitating the access to relevant information, as well as the debate and collaboration among colleagues of research projects and the presentation of works [76].

Regarding podcast as a teaching and learning supporting tool, its use has been growing fast with the process of publishing media in digital format, which can be distributed by parts or episodes over the Internet [77]. According to its particular characteristics, different types of podcast can be identified, namely: i) audio recording; ii) video recording; iii) audio and video recording; iv) audio, video and image recording (also called enhanced podcast) [78].

Podcast has brought numerous advantages in improving the quality of distance education, facilitating the publication of audio and video content and their download, motivating universities to take advantage of this facility and using podcast to record classes, seminars, material lectures in the courses, academic and scientific events that are published on the web for later use of the learning community of scientific and research contents. In this context, the use of podcast as e-learning support technology emerges as an enabler of communication, sharing of knowledge and collaboration, providing relevant information that facilitates distance learning.

3.2.3 e-Learning perpectives

The concretization of an e-learning project should consider different perspectives and components according to the training purpose and the existing resources.

As illustrated in Figure 8, the main *Components* to consider are related to:

- *Contents* - classified as non-interactive or interactive. Non-interactive contents are based on the use of simple learning support tools such as PowerPoint presentations, documents, video or audio files. Interactive contents are web-based in which animations, text, audio, video with interactivity are associated with questions, comments, useful information, or links to access resources;

- *Training and support* - include online services that provide support to individual students that include mentoring and coaching;

- *Collaboration* - involve discussions and online knowledge sharing, which can be synchronous or asynchronous, that promote communication and information about the activities that are being carried out;

- *Virtual classroom* - is a form of e-learning in which teachers give their lessons remotely and in real-time using audio, video or PowerPoint presentations using appropriate technology and connectivity [79].

Regarding the target *Users* of the training program, the implementation of e-elearnig is mainly intended to support students who are unable to attend in-person training. This can be due to factors such as: limited travel resources or geographical spread of students; unavailability due to work commitments or issues of private interest; students' location in conflict or post-conflict zones where access is restricted; cultural or religious beliefs that may limit participation in face-to-face sessions; or even in cases of students who are more timid or foreign in the process of learning the language.

The *Quality of e-learning* course depends on the following aspects: *learning-centered content* - the relevance of e-learning content in the curriculum, intended to capture the gaps and needs of knowledge and access to information; *granularity* - content must be provided in parts to facilitate learning taking into account student availability; *engaging content* - use creativity in the e-learning process to motivate and engage students; *interactivity* - it is necessary for students to interact with the trainer as a form of motivation and promotion of learning; *personalization* - given that each of the courses has its own characteristics and requirements, the advisors need to be able to use e-learning tools to keep track of the evolution of the activities of the individual orientates or students.

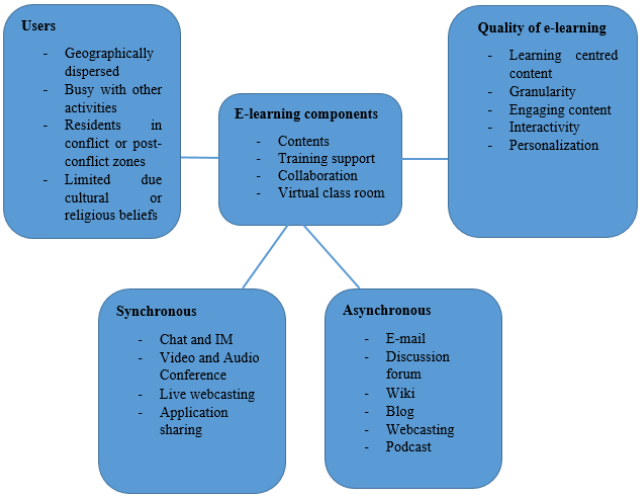


Figure 8: e-Learning multiple perspectives

Finally, e-learning can be classified into two broad categories: *synchronous* and *asynchronous*. The synchronous mode uses a learning model that initiates a course, conference or classroom meeting using Internet technologies to provide a live interaction, requiring that all participants be available at the same time. The asynchronous learning mode is described as a web-based version of computer-based training,

which is usually offered on a DVD or in the local area network of an organization. In this case, the student can access the course at any time at his own place [75, 79].

3.3 Summary

In this chapter, the crucial role of NRENs in supporting science and education has been stressed. The emphasis has been given to the framing and evolution of NRENs, their components and supported services. In particular, the distance learning concept, which is crucial for developing countries, where the access to information and the share of knowledge is difficult and/or insufficient, has been debated. The concretization of these concepts and OA strategies will be further addressed in the following chapter, through the thorough study of relevant case studies, namely Portugal and Africa.

Chapter 4

Portugal and Africa Initiatives and Collaboration

For historical reasons and language affinity with several African countries, Portugal and Africa have collaborated for centuries in multiple domains. Focusing on the research scope of the present thesis, Portugal has been a pioneer country in the implementation of OA projects and repositories, and the enrolled scientific community attests to their high success. Regarding Africa, although important steps were taken in the past two decades, the challenges for implementing NRENs and for accessing scientific information are still manyfold. This chapter is devoted to debating Portugal and Africa initiatives and collaborations in the domain of NRENs and OA, to help devise convenient proposals for science growth in Mozambique.

4.1 NRENs and OA: Portugal as a Case Study

In Portugal, FCT is the managing body of the Portuguese NREN (*Rede Ciência, Tecnologia e Sociedade* - RCTS), responsible for providing high-speed connectivity and advanced services to academic institutions and research centers. The Portuguese NREN was founded in 1987 and the evolution of its network infrastructure enabled the creation of projects supporting research and education services, especially in the last 10 years, including access to scientific content. These projects will be addressed in the following sections.

4.1.1 B-on – The Digital Library

With the creation of the Online Knowledge Library (*Biblioteca do Conhecimento Online* - B-on), in 2004, the digital library, supported by FCT, the national academic and scientific community got access to a large number of scientific publications and electronic services. Before the creation of B-on, each Portuguese institution acquired its own scientific content, being the only content available to the users of the institution. Attending to this situation, the Ministry of Science and Technology and Higher education (the then Ministry of Science of Technology) decided to centralize the budget for buying scientific publications and mandate the then FCCN, currently FCT, to acquire and manage the access to the information. The decision to

purchase access rights through a joint consortium proved to be advantageous as it allowed a stronger ability to negotiate with publishers.

For the fulfillment of B-on mission, several entities have been working together, as represented in Figure 9 and discussed below:

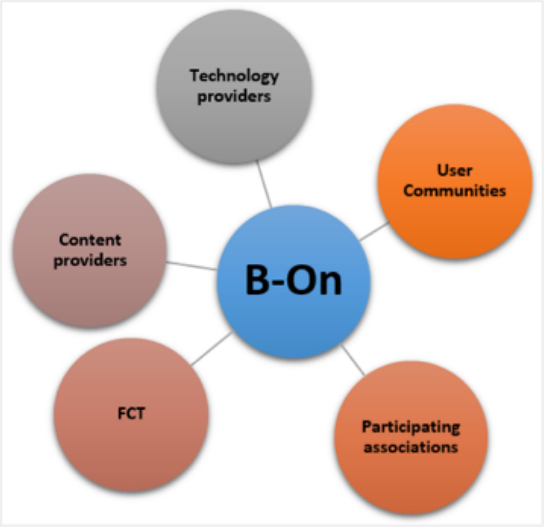


Figure 9: B-on: service entities

- FCT: which has the responsibility for political, financial and operational management. As a national public funding agency for research in science, technology and innovation, in addition to NREN management, it is responsible for the following aspects:
  - political: define, validate and approve policies related to the mission and goals;
  - operational: propose and execute operations to be performed under the strategic plan and activities;
  - financial: finance the service based on two models, regarding funding and distribution costs, respectively.
- Participating associations: primarily related to the digital libraries field, to allow joint collaboration between members and the sharing of experiences.
- Technology and content providers: the choice of content providers (publishers and other suppliers) and technologies (software, servers and other technological features) is based on the identification, selection and contract negotiation with suppliers. This process depends on the assessment of success guarantees by engaging the services provided. B-on, representing adherent higher education

and research institutions, tried to rationalize costs through centralized negotiation with publishers and other content providers.

- User communities: students, professors and researchers, physicians and librarians who develop activity in one of the member institutions of b-on have access to the full text of thousands of academic and scientific content (with peer review).

Managing contents

The B-on provides unlimited and permanent access to research institutions and higher education to the full texts of thousands of scientific journals and online ebooks from some of the most important content providers, through subscriptions negotiated at a national level. It started operating in March 2004, giving access to about 3500 titles of six publishers, and it is today a reference in accessing international scientific information. It brings together institutions of different types: higher education, scientific research and technological development, hospitals, public and private non-profit administration.

The services of B-on are based on contents, which undergo a cycle of five processes, as represented in Figure 10, namely: acquisition; access; support; administration; evaluation and monitoring, as described below:

- *Acquisition* : this process is started by the community when there is the need to purchase a particular feature, and it requires the selection and analysis of the requested content. In this case, facing the proposals and suggestions made by the community, B-on makes a first screening to exclude proposals that do not fit into the integration policies. Then, the selected proposals are analyzed to see if they are really indispensable, through questionnaires for further analysis, and according to budget availability. In case of approval of the resource acquisition, this process continues to the negotiation phase with the resource provider.

- *Access*: this aspect is related to the restrictions on accessing content through the Internet. To the member institutions allowed to access contents, B-on provides Internet access to each content provider so that the institution can register and get authorized. Remote access to information from different places is possible using VPNs, proxies and the new federated service.

- *Administration*: this involves managing all the information so that the processes of acquisition and access are successfully accomplished. This implies having the registration information of each institution (identification and contact), the catalog of periodicals and the access restrictions depending on the group to which the institution belongs.

- *Support*: this aspect targets solving problems and answering questions related to access to contents. This process handles registration, diagnosis, triage and resolution, or forwarding to a third party.

- *Evaluation and monitoring*: this process tracks the performance assessment of activities to improve service quality, based on the analysis of quantitative and qualitative indicators, reported issues, service failures, usage statistics, as well as the degree of user satisfaction.

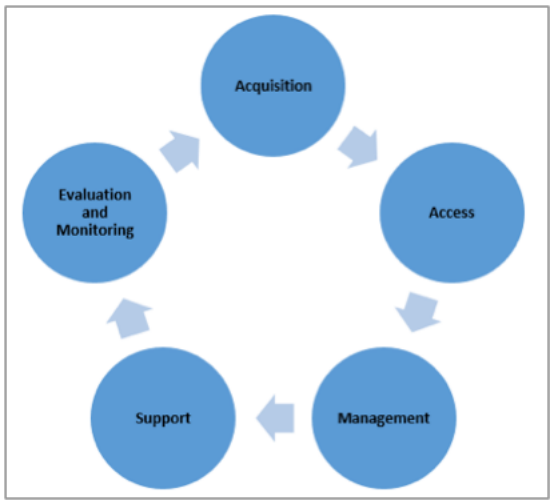


Figure 10: B-on: a cycle of five processes

Negotiating knowledge acquisition

From the creation of B-on, FCT provides the publications to the institutions linked to the NREN in two ways, "all-for-all" and "some-for-some", as described below:

- *all-for-all*: the total budget that FCT centrally manages for the acquisition of scientific publications is directed to the purchase of publications for all institutions, from a major university to a small institute, providing global access to the same publications. With this arrangement, the budget centrally managed is used to acquire contents for all participating institutions.

- *some-for-some*: as FCT cannot buy all publications available in the market, for the institutions of the consortium interested in a particular publication (at least five institutions), FCT negotiates each particular case with the publishers. If the number of institutions is smaller than five, these institutions can negotiate directly with the publishers.

In both cases, research institutes and private entities may also take advantage of this collaborative purchase, by paying from their own budget. Public entities are subsidized and private entities pay according to a predefined model. By 2012, the settlement was a payment according to the entity size (number of researchers, etc.). From 2013 the institutions pay by usage, i.e., depending on the number of downloads in the last three years. The idea is to acquire a larger number of contents, but the most relevant to the community, and to share the costs between public and private entities. If B-on fails to sign the agreement with a publisher, the exclusion affects the entire country. This strategy is part of the rationalization of costs which requires negotiation power to be successful, which is one of the objectives of B-on.

Another important aspect to face is obtaining the overall view of the most important contents to the community. As mentioned, this is obtained from downloading statistics, which allow, for example, knowing what content is actually used, and whether the users are specialized in a particular small or emergent area. In this case, they can buy and sign the content personally.

Analyzing the members of the consortium, B-on began its operation with 48 institutions in 2004, and in 2007 reached a maximum of 75 institutions. Until 2012, some institutions left the consortium, with a maximum of 3 per year. From 2012 to 2013, 12 institutions left the consortium, being integrated a total of 59 institutions in that year. The cause of this loss in membership needs a thorough analysis, being out of the scope of this dissertation. Despite the costs involved (e.g. software and maintenance) and the number of member institutions having decreased, the B-on service can be considered a success, stressed by the contents download indicators, which have grown almost continuously (from 1,996,171 in 2004 to 9,345,809 in 2013).

The statistics service of B-on aims to provide its members with data on resource usage over the years. For this purpose, Usage Consolidation of EBSCO platform is used, which allows, among other features, to obtain the following information: number of downloads per publisher, database or aggregator; more and less used periodicals; analysis of seasonality of accesses.

Each year, the B-on team produces a statistical report that aims to provide the tutelage and member institutions with demonstrative evidence of the use of the resources available at B-on. Each member institution has credentials that allow it to access its own institution's statistics. This tool has limited access and can only be accessed by librarians with access credentials (selected by each institution).

A major concern of the involved academic and research community is assuring the continuity of budget to sustain B-on. This motivates B-on to adhere to a preservation service of electronic resources called Portico [80]. There are several solutions that preserve electronic contents and provide access to institutions after unsubscribing. Portico, according to B-on analysis, seemed to be the most appropriate solution, as it

provides a wider coverage of B-on content. The strategy is to centralize the preservation process in Portico, by removing this task from libraries and publishers. The software for managing B-on content is Ex Libris, a proprietary library management system. This is an expensive software suite when considering with limited financial capacities.

4.1.2 RCAAP – The National Repository

Another service provided by FCT to NREN community is the RCAAP, the Portuguese scientific OA repository created in 2009, having as main objectives: to increase the visibility, accessibility, and dissemination of results of academic activity and national scientific research; to integrate the country into a number of international initiatives facilitating the interoperability and interconnection with other research centers, organizations financing research and higher education institutions with OA repositories worldwide.

In the last decade, Portugal has registered significant progress in the field of OA due to the dynamics imposed by the RCAAP project. Presently, Portugal is at the forefront of countries that early on began to follow and promote OA activities.

Until the end of the last century, the Portuguese scientific system was underdeveloped. At that time, the number of human resources involved full-time in research and development (R&D) activities was quite small, as well as the annual number of Portuguese articles classified in reference bases. The existing scientific collection in Portuguese libraries, especially regarding access to scientific journals, was quite limited. With the creation of B-on, the access to scientific journals in the context of Portuguese higher education libraries and research institutions significantly improved. However, despite the evolution of the country's scientific communication system, there were still problems and limitations regarding the accessibility and visibility of the national scientific production. This clarifies, to a large extent, the fact that the first OA activities in Portugal were essentially pursued by higher education institutions with the aim of promoting access to their own scientific production.

The University of Minho led the first OA initiatives in Portugal with the creation of its institutional repository, RepositóriUM, publicly presented in November 2003, and later with the definition of a pioneering institutional OA policy. However, it was only from 2006 onwards that the OA movement in Portugal gained greater expression and more widespread attention. Although there were some activities and projects (namely the holding of the 1st OA Conference in May 2005), it was only from the second half of 2006 that other important actions were taken, such as the emergence of new repositories, the dissemination of the Declaration OA of the Council of Rectors of Portuguese Universities (CRUP) and the organization of the 2nd Open Access Conference.

The CRUP signaled its support and adherence to the principles of OA to scientific literature, subscribing to the Berlin Declaration on OA to Knowledge [81]. Simultaneously, the CRUP:

- recommended that all Portuguese universities establish institutional repositories and define institutional policies requiring the deposit of their members' publications in these repositories;
- expressed its support for the interconnection and interoperability between the institutional repositories of Portuguese universities, through the creation of a single access portal to national scientific literature.

In this context, the RCAAP is a metarepository or portal that aims to collect, aggregate and index scientific content in OA, existing in the institutional repositories of national higher education entities and other Research and Development (R&D) organizations. The RCAAP portal is a single point of research, discovery, location and access to thousands of scientific and academic documents, including articles from scientific journals, communications to conferences, theses and dissertations, distributed across numerous Portuguese repositories.

In 2010, to enhance the visibility of scientific contents in Portuguese idiom, a Luso-Brazilian memorandum was established, aggregating OA sources from Portugal and Brazil, and the annual ConfOA conference was created. Internationally, RCAAP also collaborates with European projects, namely OpenAIRE and MedOAnet. As a successful Portuguese initiative, the number of documents aggregated in RCAAP exceeds currently 120 thousand.

Currently, RCAAP has available a new service: the Institutional Repositories Hosting Service (*Serviço de Alojamento de Repositórios Institucionais* – SARI). SARI is a cloud-based repository service for institutions that do not want to assure technical aspects related to the implementation of repositories, such as servers, connectivity, maintenance, backups, upgrades and monitoring. This service is provided centrally, and institutions only have to worry about administrative aspects.

Another service associated with SARI is the Common Repository, available for institutions that do not have their own repository due to their small size or low publication volume. Later on, an institution taking part in the common repository may evolve into a hosted repository, according to RCAAP policies.

Within the scope of the RCAAP project, the Scientific Journals Hosting Service (*Serviço de Alojamento de Revistas Científicas* - SARC) was created to develop the online publication of scientific journals in Portugal, facilitating the management of scientific journals and supporting best practices. The service is based on a management and publishing platform, the Open Journal System (OJS), an open source system with a wide community of users and strong impact in the OA domain. In addition to the technical aspects, the

service also provides a support service for the journal editor, as well as the necessary training to use the system, and there are periodic applications for the SARC service.

Regarding scientific data, the Scientific Data Repository Hosting Service (*Serviço de Alojamento de Repositórios de Dados Científicos* - SARDC), still in a pilot phase, intends to provide a platform for free access to data created and used in the scope of the research work of national institutions. These concepts are illustrated in Figure 11

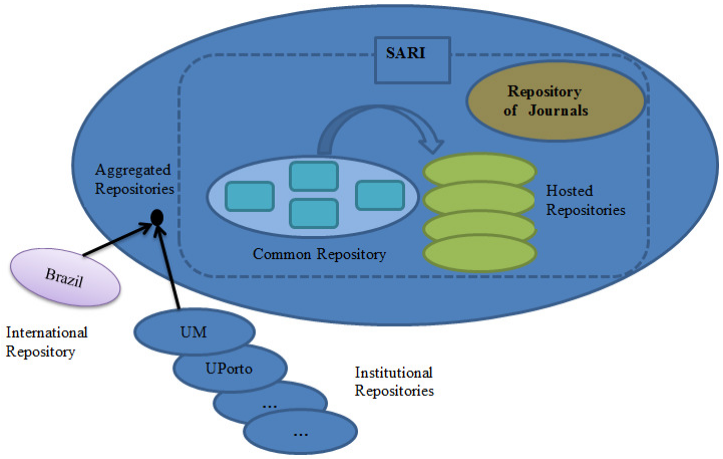


Figure 11: National repository model - RCAAP

4.1.3 Educast service

In the podcast context, FCT promotes the production and use of video among Portuguese HEIs, providing a High Definition (HD) video recording studio (and associated services) for the preparation of production kits (Educast kits) for the universities proposing a project in this area. In addition to the equipment, FCT also provides an online platform where videos can be recorded, edited and distributed. This service is called educast@fccn service [82].

Educast@fccn service is intended for the production, distribution and subsequent hosting of video contents, enabling HEIs and the research community to independently cover classes, workshops, seminars and other events of academic and cultural nature with the following target audience: the Portuguese NREN community (RCTS); HEIs; state laboratories; teachers and students.

The platform was launched in 2011 by FCT as a result of a partnership between two NRENs, SWITCH (Switzerland) and RCTS (Portugal), and the University of Porto (Portugal). The result of this partnership culminated in the implementation and adaptation of the Switchcast platform to the Portuguese reality. The video production process consists of several phases: recording, uploading to the FCT server, editing the

video, uploading the edited video to the server, and then posting it on the internet or intranet, in developed portals for this purpose.

To join the Educast@fccn service, it is required that institutions have a technical team capable of receiving the necessary training to provide technical support to teachers and end-users of the platform. The institutions that are part of the Educast@fccn service receive from FCCN, FCT Unit, initial configuration support, as well as basic training for the institution's technicians responsible for the operation of the service.

The contents produced are created within the scope of teaching and learning activities, and subsequently made available to students via the Internet and mobile devices. This platform is freely available to the Portuguese academic and research community.

4.2 NRENs and OA in the African context

In Africa there are numerous challenges for implementing NRENs and for accessing scientific information, motivating the study of the current state of national higher education and research systems, government strategies for science and their implementation, funds involved, and national and international cooperation programs for science development.

4.2.1 NRENs

NRENs in Africa began to emerge about 15 years ago, especially in Eastern and Southern Africa. The high cost of broadband access and the lack of national and international infrastructures based on optical fiber are factors that have limited their development.

Similarly to other continents, such as TERENA in Europe, the UbuntuNet Alliance is the association of African NRENs created in 2005 by 5 members established in Eastern and Southern Africa, MAREN (Malawi), MoRENet (Mozambique), KENET (Kenya), RwEdNet (Rwanda) and TENET (South Africa). To interconnect African NRENs with each other and with NRENs worldwide are the main goals of the alliance [83]. Currently, the Ubuntunet Alliance has 16 members: Burundi (BERNET), Democratic Republic of Congo (Eb@le), Ethiopia (EthERNet), Madagascar (i RENALA), Kenya (Kenet), Malawi (MAREN), Mozambique (MoRENet), Uganda (RENU), Rwanda (RwEdNet), Somalia (SomaliREN), Sudan (SudREN), South Africa (TENET), Tanzania (TERNET), Namibia (Xnet), Zambia (ZAMREN) and Zimbabwe (ZARNet).

The AfricaConnect project is one of the examples of the international collaborative effort, supported by the EC. AfricaConnect allows to interconnect NRENs in sub-Saharan Africa to an international network of high capacity, fulfilling the goals of the UbuntuNet Alliance. The interconnection of the association

members through GÉANT will support research and education in Africa, through the integration into the global research community. Researchers around the world use these advanced networks to participate and contribute to the development of international projects [84, 85, 86].

The Euro-Africa Cooperation Forum on ICT is the forum for cooperation on ICT between Africa and Europe resulting from a joint strategy adopted at the Lisbon Summit in 2007. The forum aims to foster cooperation and sharing of experiences between the two continents [5].

In relation to the West and Central African Research and Education Network (WACREN), created in 2012, the following countries are included: Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Gabon, Ghana, Mali, Niger, Nigeria, Senegal and Togo. In order to reduce the digital divide and integrate the countries of this region, snRER, the Senegal NREN is responsible for the creation of the NOC that will allow the connection to GÉANT, via Paris, through *Réseau National de télécommunications pour la Technologie, l'Enseignement et la Recherche* (RENATER), the French NREN.

The Arab States Research and Education Network (ASREN), is the association of the Arab region created in 2011, and Algeria, Djibouti, Egypt, Libya, Mauritania, Morocco, Somalia, Sudan and Tunisia are the African members. As main partner of the current EUMEDCONNECT3 (now in its third phase), ASREN also operates for the League of Arab States in North Africa. ASREN intends to expand its geographical area through the creation of the pan-Arab P & E network. In July 2015, the partner countries of North Africa (Algeria, Egypt, Morocco and Tunisia) became partners of the AfricaConnect2 project. The countries still served by EUMEDCONNECT3 are Jordan, Lebanon and Palestine.

The African panorama regarding NRENs is illustrated in Figure12. As mentioned, to promote African regional networks, the AfricaConnect project interconnects higher education and research institutions of UbuntuNet Alliance countries. The first phase, between 2011 and 2015, was supported by the European Commission on 80% of the total budget of e14.75m. This project resulted in the creation of 10 PoPs: 2 working to deliver traffic in Europe via London and Amsterdam routers, providing a 10Gbps link for IP traffic and a 10Gbps link for dedicated point-to-point circuits; 8 PoPs within the regional backbone, which covers 7 countries in the Alliance.

Africa-Connect2 represents the expansion of this project involving other African regional NRENs, in addition to the UbuntuNet Alliance, namely the countries of WACREN and ASREN. The aim was to connect North African NRENs, between 2016 and 2018 to GÉANT and, through it, to connect other NRENs of the world at reduced bandwidth costs. This enlarged connectivity provided opportunities to introduce advanced services, such as e-Education, and benefits international scientific collaboration in different research areas, including the areas related to climate change, food security, malaria and other infectious diseases affecting

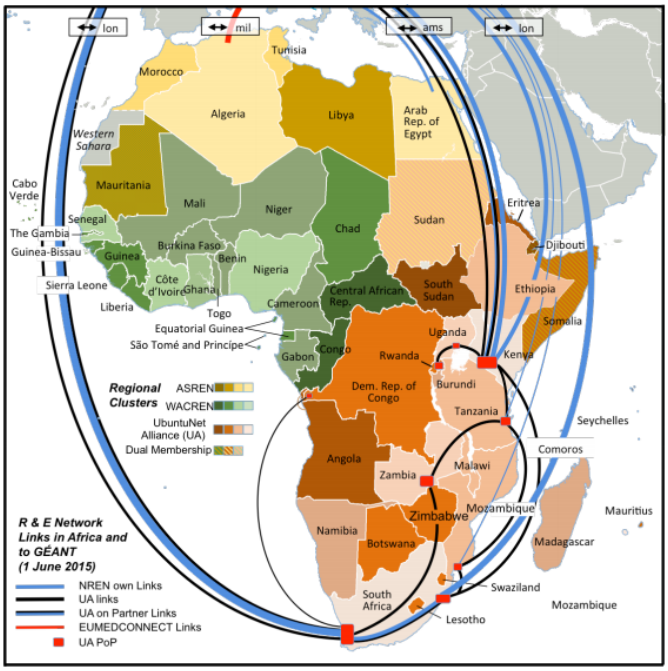


Figure 12: African NRENs [68]

these countries [68, 87].

AfricaConnect3 represents the third phase of the AfricaConnect project, building on the success of two predecessor projects in supporting the creation, development and use of advanced, reliable Internet connectivity for the teaching, learning and research communities of Africa. AfricaConnect3 is co-funded by the EU and delivered locally by regional organizations - UbuntuNet Alliance, WACREN and ASREN, together with GÉANT [88, 89].

Similarly to the two previous projects, AfricaConnect3 also builds on the achievements of the EUMED-CONNECT3 project. Co-funded by the EU, EUMEDCONNECT has provided a high-capacity dedicated internet network for the research and education communities across the southern and eastern Mediterranean region since 2004. In 2015, its North African partner countries migrated to AfricaConnect2 [88, 89].

AfricaConnect3 will connect Africa to unlimited possibilities by improving and enabling access for researchers, students and institutions to digital infrastructures and technologies. African students and researchers will benefit from high-speed, reliable broadband connectivity and services such as eduroam, access to innovative e-learning tools and advanced research resources, and collaborative learning and research with peers around the world. African NRENs will benefit from capacity building to upscale human resources output, participation in global research and education (R&E) events for increased exposure, knowledge transfer and exchange.

4.2.2 Accessing knowledge

Accessing knowledge has been a major challenge of the African continent. The access to scientific literature is still a huge struggle for most of HEIs and research centers due to financial constraints to purchase content from commercial publishers. To face this shortfall, several African institutions assist the scientific community needs resorting to organizations that support and promote access and sharing of knowledge. These organizations, such as the International Network for the Availability of Scientific Publications (INASP), the African Academy of Sciences (AAS), the Research4Life, negotiate with commercial publishers to provide scientific literature for free or at low cost, and to support the creation of sustainable national library consortia, open access publishing and building of institutional repositories of local contents, libraries, and intellectual property rights.

The challenges of deploying OA repositories in Africa have been addressed in [90]. Regarding the overall picture of scientific research, the author stresses that despite its ethnic and cultural diversity, and abundance of natural resources, Africa faces problems of post-colonial era: poverty; political instability; corruption; diseases and armed conflicts that undermine their growth.

In terms of accessing information freely and without restrictions, the OA movement has been growing, bringing many advantages to the development of scientific production and innovation in Africa. In this regard, The United Nations Educational, Scientific and Cultural Organization (UNESCO) has promoted OA actions, primarily focused on scientific information resulting from public funding. These actions, undertaken in collaboration with its strategic partners, aim to raise awareness about the benefits of OA among policy makers, researchers and knowledge managers, assisting the development and promotion of OA with special attention to African and other developing countries.

Currently, Africa has 193 repositories [22] spread over only 25 of the 54 independent countries. As illustrated in Table 1, South Africa is on top of the list with 44 repositories, followed by Kenya with 43, both members of UbuntuNet Alliance. From the five countries of CPLP (the Community of Portuguese Language Countries) located in Africa, only Mozambique and Cape Verde take part in the list, being the repository "Knowledge Portal of Cape Verde" physically hosted at the UM in Portugal. However, even these countries are not taking full advantage of their institutional repositories, and the percentage of scientific publications available in OA could be higher. For countries such as Angola, Guinea-Bissau, and São Tomé and Príncipe, it is not yet possible to foster OA, because they lack a repository that can fulfill this function. It is true that the financial, technological and human resources to make this possible may not be sufficient to carry out the necessary actions.

In the same way that Mozambique worked cooperatively to create the national repository SABER, it is

important to think about the creation of an inter-institutional repository that brings together the scientific production of the Portuguese-speaking African community, with international help and, especially, the help of more advanced Portuguese-speaking countries such as Portugal and Brazil.

UbuntuNet Alliance Countries	Number	Other Countries	Number
South Africa	44	Nigeria	30
Kenya	43	Algeria	20
Tanzania	14	Egypt	8
Sudan	12	Ghana	6
Uganda, Zimbabwe	11	Botswana, Libya, Morocco, Senegal	3
Ethiopia	5	Cape Verde, Lesotho	2
Mozambique, Namibia, Rwanda, Zambia	2	Cameroon	1
Somalia, Malawi	1	Other 29 of 54 African Countries	0
Madagascar, D.R. Congo, Burundi	0	Total of repositories in Africa	193

Table 1: Repositories in Africa

Scientific journals play a key role in the global knowledge society. The production of scientific OA journals in Africa is still scarce according to the Directory of Open Access Journals (DOAJ) [91]. The "Open Access for Africa" event is a recent initiative promoting the discussion of issues related to scientific research, the quality of higher education and the role of OA journals in the African continent [92].

Regarding scientific journals indexed in DOAJ, according to Table 2, only 11 of the 54 African countries are represented. South Africa, with 113 journals, is at the top of the list, followed by Egypt with 47, and Morocco with 28 OA journals. Regarding the UbuntuNet Alliance countries, in addition to South Africa, Ethiopia with 7 and Kenya with 5 journals, respectively, take part of this list. Of the 5 Portuguese-speaking African countries, only Angola is included in this list with 3 journals, namely, Revista Angolana de Ciências, Revista Órbita Pedagógica and SAPIENTIE.

Considering African Journals OnLine (AJOL), which promotes the access to scientific literature collections produced in Africa, AJOL hosts 527 African journals including 270 Open Access Journals from 33 countries [93]. Table 3 presents the top 10 of the 33 countries represented on the portal. As shown, Nigeria with 222 indexed journals and South Africa with 96, are the countries that lead the list, followed by Ethiopia and Kenya with 30 and 29 journals, respectively. Regarding the UbuntuNet Alliance countries, in addition to South Africa, Ethiopia and Kenya, the list includes Tanzania with 19, Zimbabwe with 12, Demo-

Country (DOAJ)	# Journals (DOAJ)
South Africa	113
Egypt	47
Morocco	28
Algeria	19
Nigeria	9
Ethiopia	7
Ghana	6
Kenya	5
Tunisia	4
Angola	3
Libya	3

Table 2: Journals in DOAJ

cratic Republic of Congo with 1, Madagascar with 1, Malawi with 4, Mozambique with 1, Rwanda with 7, Sudan with 3 and Zambia with 2, totaling 12 countries [93]. With regard to Portuguese-speaking African countries, only Mozambique is included in the list with the journal "The African Journal of Governance and Development". This publication is co-managed and co-published by institutions in South Africa and Mozambique, not being in open access.

Despite that, on the African continent, efforts in favor of OA have been substantial involving different countries. Most of the initiatives are located in Anglophone African countries, to a lesser extent Francophone Africa, while in Lusophone African countries, the situation is still very incipient, both through the golden and the green way. The results so far tend to show that most teachers and researchers are not aware of library portals and institutional repositories. Most users affirm the importance of electronic journals for their teaching and research activities, despite the difficulty of the language, as most documents are in foreign languages, especially in English. Based on the data presented, it can be concluded that the number of journals in OA in Portuguese-speaking African countries is still scarce. Furthermore, these are not integrated with the rest of OA journal titles in international directories, such as DOAJ, or African ones, such as AJOL. This fact limits the visibility and global dissemination of the research carried out in this community of countries. As for the scientific production of authors from Portuguese-speaking African institutions, the still-emerging scientific status of these countries leads to their subordination and/or dependence on foreign and international institutions and publishers. Most of the works are published in magazines of

commercial publishers and are works in collaboration with researchers from foreign institutions.

Country (Top 10)	# Journals (AJOL)
Nigeria	222
South Africa	96
Ethiopia	30
Kenya	29
Ghana	27
Tanzania	19
Egypt	14
Uganda	12
Zimbabwe	12
Cameroon	8

Table 3: Journals in AJOL

Regarding the OA to research data, the panorama is very immature. In the ROAR portal, Africa has only one repository of this nature, the South African Data Archive (SADA) [94].

Concerning OA policies and mandates in Africa, the numbers are also low, despite the efforts that have been made by various OA promoting bodies. According to the data presented in Table 4, there are only 34 institutions with OA policies and mandates in Africa, registered in The Registry of Open Access Repository Mandates and Policies (ROARMAP), belonging to the 8 following countries: Algeria, Ghana, Kenya, South Africa, Burundi, Tanzania, Nigeria and Zimbabwe. Kenya leads with 15 education and research institutions with OA policies and mandates, followed by South Africa with 11. 29 OA policies and mandates belong to 4 UbuntuNet Alliance countries, in addition to South Africa and Kenya, Tanzania and Zimbabwe are on the list [94] [95]. As illustrated, no Portuguese-speaking African country has registered open access policies in ROARMAP, and only a few institutions in Anglophone African countries have this type of policy.

The first higher education institution to adopt an OA mandate was the University of Pretoria in 2009. Based on the data presented, it is relevant to examine the barriers that impede the implementation of OA initiatives in institutions and research funding bodies. Governments must design appropriate policies for the African context, create programs that promote scientific research and encourage OA. The creation of OA policies and mandates will improve the visibility of the academic community production, so that the continent, instead being a mere consumer of science, can generate and share their production with mechanisms that protect intellectual property.

Country	# Institutions (OA Policies and Mandates)
Kenya	15
South Africa	11
Algeria	3
Zimbabwe	2
Burundi	1
Ghana	1
Nigeria	1

Table 4: Policies and mandates

4.2.3 e-Learning initiatives

Within the framework of the African Union (AU), the Vision Africa 2063 program demonstrates the continent's need to create conditions for improving the access to education, exploring ICT as a way to foster economic and social development. It is mainly in rural areas and in sub-Saharan Africa that a new paradigm for e-learning is needed, as fifty-six million people in the region between 15-24 years old have not completed public school. The literacy rates of young people are still only 70% and women account for two-thirds of all illiterate adults [96].

In the case of Botswana, the University of Botswana (UB), more specifically the University of Botswana Library (UB Library), has faced many challenges in order to take advantage of the use of Web 2.0 technologies and podcast as tools to support e-learning environments that have proven to be appropriate in learning-centered environments. In 2008, UB approved its Learning and Teaching Policy and Research Strategy to "*provide guidance to all employees on the implementation of learning and teaching processes*" and foster the development of research in the institution. Previously in 2000, the UB Library and the Centre for Academic Development (CAD) began a collaboration process with the objective of integrating communication technologies in learning and teaching, and an Electronic Learning Support Center for academic staff was created as a way to include educational technology in the curriculum, facilitating the delivery and creation of contents. From this initiative, classrooms for e-learning, videoconference and WebCT were built as an e-learning management system. In addition, UB used an e-learning approach where, through different traditional and digital methods and media, contents are integrated into learning and teaching [97].

In the case of Kenya, according to the study conducted in [76], in recent years most Kenyan public

universities have been adopting e-learning as a new approach to teaching and learning. In 2015, there were a total of 22 public universities enrolled and more universities are being compelled by the government under Kenya Vision 2030 to introduce e-learning and blended learning as an alternative to increase access to higher education in the country. In more detail, Kenya Vision 2030 is the country's framework development program for the period 2008-2030, which aims to make Kenya a middle-income country and to enable a better quality of life for its citizens by 2030.

Despite the efforts, among the universities that initiated the implementation of e-learning, in 2015 only 11% of Kenyan university students were taking their courses using combined mode e-learning. The University of Nairobi, for example, started its e-learning project in 2004 with a well-tested platform called Wedusoft (a Chisimba structure). Kenyatta University launched its e-learning project in 2005 and the Jomo Kenyatta University of Agriculture and Technology in 2006, and both adopted Moodle as e-learning platform. Moi University started in 2007 with MUSOMI (personalized from the Chisimba structure) as the e-learning platform. However, the implementation of e-learning by these universities is still not effective due to several challenges that have to be overcome, namely the need for training in e-learning technologies and the aversion to change, since both teachers and students need adequate technical skills to effectively use the e-learning tools.

In summary, the implementation of e-learning is at an early stage in most Kenyan public universities and faces numerous challenges ranging from technological to organizational and pedagogical issues.

4.3 Summary

In this chapter, the steps and initiatives of Portugal and Africa towards the evolution of NRENs, open science, and distance education have been surveyed. Starting with the successful Portuguese case study, the way the country addressed advanced services for its academic and research community, provides an important perspective and gives directions that may be followed to foster science in developing countries. Regarding Africa, understanding the steps already taken and their real outcome facing the African countries' reality was considered also crucial to help devising an appropriate open science model for Mozambique. According to this vision, in the next chapter, the emphasis of the discussion will be given to the Mozambique ecosystem, to realize the initiatives and challenges of this specific African country.

Chapter 5

Mozambique Scientific Ecosystem

Mozambique is an official Portuguese-speaking country located on the eastern coast of South Africa, with 801 537 square kilometers of territorial area, 11 provincial capitals, 52 district offices, and 31 administrative posts. In 2021 the population was estimated at 30,832,244 inhabitants, of whom 14,885,787 were men and 15,946,457 women, 34.02% living in urban areas and 65.08% in rural areas.

For more than two decades, several strategic initiatives in the domain of Information and Communications Technology (ICT) and scientific research arose, aiming at fostering the country's development level. Nevertheless, multiple aspects undermine their full success and, therefore, many open issues remain to be tackled to strengthen science and education in the country.

This chapter is entirely devoted to discussing the Mozambican scientific framing, in its multiple perspectives. In this way, initiatives and the current state of higher education, OA, distance learning, and technological infrastructures, more precisely the Mozambique NREN, are discussed.

5.1 Strategic plan

The framework for the development of information society in Mozambique, the ICT policy adopted in 2000, defines main objectives to combat poverty and improve Mozambicans' life conditions. Ensuring the production and access to knowledge are some of the fundamental aspects of the ICT policy for Mozambique to become a relevant and competitive partner in the global information society. Regarding the National Research System (NRS), only in 2000 emerged a ministry specifically dedicated to science and technology, now called the Ministry of Science, Technology and Higher Education (*Ministério da Ciência, Tecnologia e Ensino Superior* - MCTES). In this context, a strategic plan was approved for scientific research in the country to support the development of the NRS. Thus, the NRS is managed by the government through the MCTES. In 2005 was created the National Research Fund (NRF), the main government agency responsible for funding research in Mozambique. The promotion of programs, projects and actions in the field of

scientific research in accordance with the strategic priorities of the country are the main objectives of the NRF. From the NRF budget to support research projects, mainly resulting from external support, a large part of the investment is dedicated to the training of human resources. Under the Science, Technology and Innovation Strategy of Mozambique (*Estratégia de Ciência, Tecnologia e Inovação de Moçambique* - ECTIM) launched in 2006, to strengthen the National System of Science, Technology and Innovation, began the project for the development of the country NREN, called MoRENet. The challenges for the effective implementation of MoRENet are enormous taking into account economic, social, technical, technological, and infrastructural aspects. In this context, there is still much to do and a great commitment and pressure to put MoRENet fully operational. The same occurs for the support of advanced services to the enrolled community.

5.2 Higher education

UEM is the oldest institution of higher education in Mozambique. Founded in 1962 under the name of General University Studies of Mozambique, in 1968 it was renamed to University of Lourenço Marques (ULM) at the time which ascended to the level of University. In 1976, resulting from the reforms that had occurred and as a result of the country's independence, it was renamed Eduardo Mondlane University. Before independence, the training of most Mozambican citizens was minimal or nil, and the UEM curriculum reform that occurred at that time included new curricula and Bachelor's degree courses, to respond quickly to the needs of the labor market [98]. Currently, Mozambique has around 50 HEIs, however, in the world ranking, Mozambican universities are in a low place. UEM is considered the best HEI in the country.

The recent history of Mozambique is, generically, divided into two main moments, almost always based on the dominant political-economic orientation: a first moment that goes from 1975 to the beginning of the 1990s; and a second moment since then even today. The transition period is characterized by the revision of the Constitution of the Republic of Mozambique, in 1990. As mentioned, in the period before 1990, all higher education was owned by the Government and was based on centralized planning. However, with the entry into force of the new Constitution of the Republic of Mozambique and the opening of the country to the market economy, a new scenario was opened, in which private entities could establish HEIs in Mozambique.

In this sequence, the major milestone in this last period was the institutionalization of the entry of private actors into higher education in 1993, materialized by the 1st Law on Higher Education n°1/93, of

24 June, however without regulation. Thus, with the approval of this law, legal persons governed by private law, such as associations, societies, foundations or cooperatives, could create HEIs. With this opening, the massification of higher education was notorious, with a significant growth in enrollments and a territorial expansion of this teaching subsystem, from 3 public HEIs in 1993 to 53 in 2017, being 19 public and 34 private.

Until 1998, HEIs in Mozambique only offered undergraduate courses, and only from 1999 onwards did start offering postgraduate, master, and doctoral programs. Regarding the teaching staff, the statistics in Table 5 indicate that, in 2004, there were 1026 full-time teachers, of which 624 graduated, 217 Masters, 147 Doctorates and 38 trained at other levels (Bachelor and Diploma). In 2017 (more recent data is not available) the numbers grew to 4989 teachers, of which 1876 were graduates, 2299 Masters, 704 Doctorates and 110 graduated at other levels, corresponding to bachelors and diplomas (therefore, not part of the three training cycles described by the higher education legislation in force in the country) [99].

Teachers (full-time)	2004	2017
Graduated	624	1876
Master	217	2299
Doctorate	147	704
Bachelor's degree and Diploma	38	110
Total	1026	4989

Table 5: Full-time teachers (2004 and 2017)

It is noteworthy here, the excessive increase in private HEIs, however, this increase is not proportional to the number of students enrolled, as illustrated in Table 6. The statistics indicate that the increase in the number of students in public HEIs grew from 15,113 in 2004 to 119,974 in 2017. Conversely, in private HEIs, the number of students was 7,027 in 2004 and evolved to 80,705 in 2017 [99].

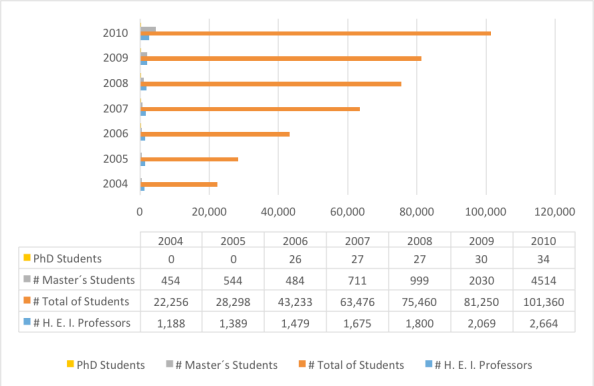
Mozambican higher education takes in 6% of students who finish high school and the government intends to increase this number. Mozambican higher education has nearly 200,000 students spread over 53 institutions, including private and public, with around 800 courses to be taught. In South Africa for example, Mozambique's neighboring country, 22% of students who finish secondary school enter higher education.

A more detailed view of the panorama and past evolution in HEI regarding the students' and professors' community is provided in Figure 13. As shown, there is a significant increase in the number of master's

HEIs	# students in 2004	# students in 2017
Public	15113	119944
Private	7027	80705
Total	22140	200649

Table 6: Students (2004 and 2017)

degree students, from 454 in 2004 to 4514 in 2010, which represents about 1,000% of increase. As regards doctoral students, only in 2006 were registered their existence, growing from 26 PhD students in 2006 to 34 in 2010 [100].



	2004	2005	2006	2007	2008	2009	2010
PhD Students	0	0	26	27	27	30	34
# Master´s Students	454	544	484	711	999	2030	4514
# Total of Students	22,256	28,298	43,233	63,476	75,460	81,250	101,360
# H. E. I. Professors	1,188	1,389	1,479	1,675	1,800	2,069	2,664

Figure 13: Detailed Mozambique higher education evolution (available from 2004 - 2010)

The growing number of HEIs in Mozambique was not accompanied by the creation of appropriate infrastructure conditions to ensure a good quality of education. In this context, some institutions are operating without libraries, laboratories, and other appropriate facilities for access to knowledge. To address this gap the Mozambican government approved in 2010 the Licensing Regulation and Operation program, requiring appropriate infrastructure and subjecting HEIs to inspection. Currently, all created HEIs must meet conditions that guarantee minimum standards of educational quality.

Another aspect to consider is that the rapid growth in student numbers between 2004 and 2017, was not accompanied by an appropriate plan of supporting academic staff. According to the data presented in Table 6 and Figure 13, the evolution of academic staff quadrupled while the number of students grew 7.9 times in public HEIs and 11 times in private HEIs.

Regarding the scientific research community, to meet the needs in terms of research growth, the MCTES Human Resources Development Plan for Science and Technology was approved in 2006. The focus of this plan was to train the researchers in developing their activity in research centers. Therefore,

the reports on the output of this plan do not include statistics regarding teachers, who also develop research activities. Under this plan, by 2025, it is expected to reach about 6595 researchers in practice in priority areas identified, namely: engineering and technology; medical sciences; agricultural sciences; and natural and exact sciences. When studying the evaluation of researchers in the country, from 2007 to 2014, based on the number of MCTES grants for undergraduate studies and scholarships for master and doctoral projects, about 70% respect the master's level and only 30% are for doctorate level. During this period, the two main institutions that support higher education in the country financed about 1600 scholarships. For the next 10 years, from 2015 to 2025, mechanisms should be created so that during this period the defined MCTES goal is achieved. Therefore, it is expected that in 10 years the Mozambican state will form about 5,000 new researchers.

5.2.1 Scientific research and production

In the beginning, the major challenge of the NRF was the quality of research proposals. When it launched the first call, the quality of the project proposals submitted was very weak, so the NRF introduced a course on research methods and preparation of proposals, in which participated teachers, researchers, technicians and innovators. Today it is already a culture, the NRF annually conducts some regional courses on research methodology and proposals, which result in the increasing of proposals, both in number and in quality.

However, generically, the quality of research in Mozambique is still unsatisfactory and of limited application. The Mozambique Science, Technology and Innovation Strategy (MOSTIS), for the period 2006-2016, stimulated the growth of research activities with the introduction of research funding mechanisms and bilateral treaties, and other international competitive funds. In addition, the MOSTIS defined strategic priority areas of research and corresponding actions, however, despite having initiated various activities, a long-term vision is still lacking.

Considering the evaluation carried out since its inception in 2006 until 2014, the NRF has funded 250 projects at national and international levels which reflects the interest in scientific research and in solving problems. One of the outcomes of the creation of NRF is that researchers had not competitive culture and began to improve their skills, being not afraid to compete. The challenge is that they also compete for existing global funds for research.

According to Figure 14, reporting the bibliometric analysis in Scopus and Scimago databases between 2005 and 2013, before and after international collaboration, there was a significant growth in produced documents wherein at least one of the authors belongs to a Mozambican institution: Scopus, starts with

78 documents and reaches a maximum of 235 documents in 2013; Scimago, starts with 72 documents and reaches a maximum of 222 documents in 2011. Note that this growth is related to new science policies, technology and innovation in the country [101, 102].

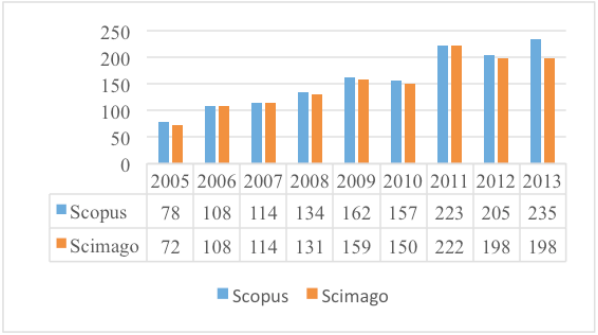


Figure 14: Mozambique research output (available from 2005 - 2013)

5.2.2 Accessing scientific literature

As mentioned in Section 4.2.2, access to knowledge in the African continent has been a major challenge, and several organizations, such as INASP, AAS, Research4Life, and Electronic Information for Libraries (EIFL), intend to help to change this panorama.

The lack of budget in research and education institutions to provide the community with international scientific content in different fields is a big drawback. The effort of UEM in this context enabled through the INASP program with whom UEM has worked since 2001, regards the negotiation of access to journals and books with international publishers without charge or at a low-cost price for Mozambican institutions. With INASP support, Mozambique can access about 90% of the publications paying 10% of their real value. The acquisition model of scientific literature through commercial publishers in Mozambique is not associated with the academy of sciences of the country. In this sense, UEM is the national coordinator of the consortium of universities supported by the INASP project, being responsible for channeling the budget available for paying access to publications for the HEIs in the country. Currently, all Mozambican institutions of higher education, public and private, access $\sim$ 23 000 titles. However, the utilization rates are very low, ranging between 5-10% of downloads per year to the available titles, with a cost of $\sim$ 30,000 dollars annually.

Note that, there are other organizations with programs supporting access to scientific literature from specific areas that Mozambique and other developing countries use, namely HINARI, for biomedical, Online Access to Research in the Environment (OARE), in the environmental field and AGORA for agriculture.

5.3 SABER - The National Repository

The lack of scientific information is a reality in Mozambique and to reduce this limitation, the National Repository SABER was created in November 2009, to serve as a common platform for the involved 6 institutions: Judicial Training Centre; Higher Institute of Science and Technology of Mozambique; University Eduardo Mondlane (UEM); Pedagogical University; Polytechnic University; and University of St. Thomas of Mozambique. SABER aimed to store scientific and academic documents produced in or related to Mozambique [103], and was supported by the Ministry of Education and the World Bank for resource acquisition. The technical collaboration with UM in Portugal revealed very helpful for setting up the repository, facing the experience of UM in this area. SABER was physically hosted at UEM, the oldest institution of higher education in the country, which was responsible for the technical support.

In fact, the OA movement in Mozambique is recent and most of OA initiatives are being conducted by UEM, which tries to give visibility and preserve the academic and scientific production of national institutions. After nearly five years, SABER stored in 2014 about three thousand documents, including teaching materials, monographs and dissertations. In more detail, UEM had more than 2900 documents deposited, being the institution that contributed with the largest number of documents (98%), and the remaining documents (2%) were related to other member institutions (Judicial Training Center, Pedagogical University and Polytechnic University). The Higher Institute of Science and Technology of Mozambique and the University of St. Thomas of Mozambique institutions, although integrating the repository, have no contribution in terms of contents. Considering the evolution of documents in SABER repository by year, illustrated in Figure 15, it is visible that 78% of documents report to the time period previous to SABER creation. Taking into account these numbers and the inexistence of national and institutional policies, it is therefore important to understand and respond against existing barriers that limit the success of OA in Mozambique.

SABER was the first repository in Mozambique, and the first in CPLP countries in Africa. The software adopted to implement the repository is Dspace. The administrative workflow tasks related to the deposit of documents in the repository were shared between the participant institutions. Until 2019, it was, evident the need to establish policies aiming at involving a larger number of institutions in SABER. In addition, the then Ministry of Science and Technology (MST), now MCTES, had shown interest in collaborating with resources and maintenance to support the evolution of SABER.

Despite still being registered with OpenDoar, since 2019 the SABER repository is no longer accessible. In this context, the Mozambican academic and scientific community loses some of its most valuable

collections, around 3000 historical documents are no longer accessed. The 98% of scientific literature in the SABER repository that belonged to UEM was not transferred to the new UEM repository. Thus, although the repositories of the UEM and the Catholic University of Mozambique currently exist, Mozambique has taken a step back in the advance of open access.

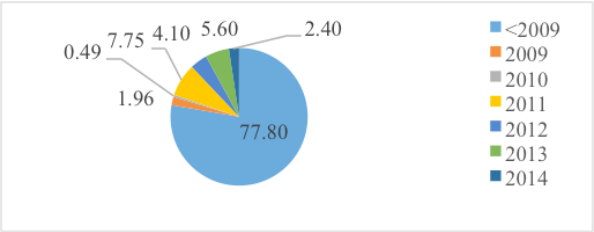


Figure 15: Annual distribution of documents in SABER repository

5.4 OA journals: the case of RC-UEM

Scientific journals play a crucial role in the generation and sharing of knowledge, and peer reviewing contributes to improving the quality of the publication system. With this frame, UEM created in 2010 the Scientific Journal of UEM (RC-UEM), a biannual OA journal aiming at presenting the results of Mozambique scientific production undertaken in national institutions of higher education and research. The journal covers eight specific areas: (i) biomedical sciences and public health; (ii) engineering, architecture, urbanism and technology; (iii) letters and social sciences; (iv) natural sciences and environment; (v) agricultural, forestry and veterinary sciences; (vi) science of education; (vii) legal sciences; and (viii) economics, management and development. The first series of RC-UEM was launched in 2012. Whilst its importance is recognized, RC-UEM project faces numerous difficulties due to the research landscape and quality of scientific production in the country. For example, the 2013 call for papers resulted in 70 submissions, and 14% of approvals after the peer reviewing process (involving national and international reviewers).

The main challenges faced by the RC-UEM and other endogenous magazines are mainly related to the following aspects: (i) the lack of a national scientific community and the geographic boundaries of existing research lead to a shortage of submissions. Most of Mozambican researchers work in cooperation with international institutions (for instance, involved in their MSc and PhD studies). Even when the students return to Mozambique, it is common to maintain the external link and publish their work abroad. This is one of the biggest barriers to the creation of a scientific community turned inward; (ii) facing the lack of contents, the few endogenous magazines “die” prematurely, after two or three series; (iii) the reviewing process takes too long to be completed, impairing the process of launching a magazine edition. Moreover,

as previously stated, most of the submitted works are not accepted. Facing this scenario and the absence of national and institutional policies for scientific journals in the country, UEM is committed to building its institutional policy of publication and registering RC-UEM in the African directory of scientific journals.

5.5 e-Learning as an education alternative

After independence, the country had to deal with severe problems related to the weaknesses in the education system, the lack of access to education for the majority of citizens, the high rates of illiteracy, the lack of qualified teachers and good management practices in the education system.

At present, the government of Mozambique recognizes and values the importance of distance learning and has launched strategies and programs related to education, science and technology. As result, from the about 50 higher education institutions in Mozambique, some of them resort to advanced e-learning as an alternative to classroom teaching to cover the existing gaps in the access to education for Mozambicans. The National Institute of Distance Education (*Instituto Nacional de Educação à Distância* - INED) is the institution responsible for creating regulations, policies and parameters of distance education, demanding quality standards for adherent institutions, whether national or international, public or private.

5.5.1 National initiatives

In February 2017 the Ministry of Education and Development of Mozambique launched the Distance Education Program (Programa de Ensino Secundário à Distância - PESD2), which is designed for young adults in the 11th and 12th classes of secondary school to learn remotely. In its first phase, the program was available in seven provinces for all students who have completed the 10th grade, and for young people who, for some reason, cannot attend school during the day or cannot reconcile their studies in parallel with other activities. Classes were held with support from an online platform and qualified tutors. The training started with improving students' skills in the use of the e-learning platform, so they could study anywhere, as long as they had access to a computer, tablet or cell phone with an Internet connection. The Teaching and Learning Centers involved have computers, ensuring that the student also receives face-to-face support from a tutor and from distance. During the e-learning process, three types of evaluation were carried out: self-evaluation; end-of-module test; and final exam. In the first, the student solves exercises to evaluate his learning. The second test allows the student to move from one module to another, and the last one is the national exam prepared by the Ministry of Education for all general secondary school students.

The Distance Learning Program for the first cycle students was launched nationwide in 2008 and in 2016 statistics indicate that there are about 314 Distance Learning and Education Support Centers in the country, reaching a total of 32,423 students. In terms of HEIs, the regulations, policies and parameters of distance education, demanding quality standards for adherent institutions, whether national or international, public or private, are carried out by the INED.

According to available data from 2014 of INED, Mozambique has 14 institutions offering distance learning courses, having just over 49,000 students enrolled, distributed in the following way (in decreasing order of number of students): (i) INED, with more than 33,500 students and 3 courses; (ii) Catholic University of Mozambique (Universidade Católica de Moçambique - UCM), with more than 8 thousand students and 15 courses; (iii) Pedagogical University of Mozambique (UP), with more than 3,800 students and 5 courses; (iv) Instituto Superior Monitor (ISM), with about 1,500 students and 4 courses; (v) Institute of Training in Public Administration and Autarchic, with about 1,460 students and 1 course; (vi) Eduardo Mondlane University, with more than 920 students and 4 courses.

5.5.2 Exploring international collaboration

The creation of a doctoral program in Education Sciences in Mozambique arose from the need to train teachers from the Catholic University of Mozambique (UCM) and from the interest of the Catholic University of Portugal (UCP) to actively collaborate in this project. The organization of the course in the northern region of Mozambique, more concretely in the province of Nampula, where a UCP campus is located, required the adoption of a training model that ensure that the curriculum developed in Portugal was also fully complied with this new context. Thus, it was important to comply with the content established in the curricular plan and, due to the impossibility of doing it face-to-face, an e-learning model was defined with a plan centered on Mozambican reality [104].

The interest of candidates other than the UCM to attend this course (e.g., Nampula institutions such as the National Statistics Institute, the Military Academy, the University of Lurio, public institutions that showed interest in integrating the group), was an opportunity for training 26 Mozambicans at the 3rd cycle level. This involved the need to deal with a large group in the course, originally envisaged for 16 PhD students.

The doctoral course was structured and developed by the UCP taking into account its human resources (qualified teachers) and materials (availability of e-learning platform to support the learning process, adequate pedagogical materials and tutorial communication). Taking into account that the teaching process as a whole could not be done in person, a teaching model was defined considering two weeks of face-to-

face training at the beginning of each semester and then online training using face-to-face sessions. The face-to-face sessions were aimed at introducing the topics that doctoral students would have to develop in the subsequent period of online work, as well as individual tutorial follow-up for those who asked for it or for whom the teachers felt relevant.

In the course platform, the institutional cooperation was supported in three important ways: (i) content repository, fundamentally constituted by scientific literature that the teachers put online to support the training process; (ii) asynchronous communication space, for the appropriate and deliberate use of the forum area; (iii) space for increasing digital literacy, since the ICT and e-learning space support various tasks performed by the doctoral students. The most relevant were: the process of habituation to the use of Skype for individual tutoring sessions; the use of blogs for the organization of individual portfolios; and the use of Mendeley as a tool for bibliographic organization.

5.5.3 Discussing the challenges

In the study mentioned above, a training model focused on distance learning methodologies was considered. The students' lack of proficiency, digital skills and difficulty in accessing Internet tools, led to the use of blended learning strategies, more appropriate for this context. The students and teachers physically separation in the geographic space, the urgent need to perform the training, the establishment of a clear administrative and pedagogical relationship and the possibility of using the Internet for typically asynchronous communication functions were the reasons in the basis of the devised e-learning model.

The reasons why it was not possible, nor desirable, to take a distance course only, are based on logistical and contextual conditions, namely the quality of the Internet services that the students had access to. In fact, many difficulties were encountered during the course impairing a stable use of services: the access was difficult; the connections were frequently interrupted; the bandwidth was reduced in content sharing. These aspects inhibited the planning of synchronous collective sessions using, for example, webconference software such as Adobe Connect or Webex. Several attempts were made in this direction, but the model was soon abandoned given the poor quality of connectivity. In addition, most of the students are accustomed to the close presence of teachers and hardly dispense the personal contact, crucial to promote the socialization that facilitates the process of learning construction.

5.6 Technological infrastructures

Developing countries continue to face huge challenges in providing connectivity, especially in rural and remote areas. In these regions, where broadband access is so far costly, universal access funds can be used to subsidize new broadband infrastructures and new network deployments.

As example, Chile, Turkey and Malaysia governments have created and strengthened their universal policies and funds to extend voice, data and internet services to citizens, including more remote locations, in many cases opting for the use of wireless technologies to reduce costs. Globally, and more specifically on the African continent, several countries have made progress with similar projects and policies [105].

In Mozambique, where there are less profitable rural areas and where there are few investments in telecommunications infrastructures (data, voice, and Internet), the Universal Service Access Fund (Fundo de Serviço de Acesso Universal - FSAU), under the management of the National Institute of Communications of Mozambique, allowed the financing of projects and programs focused on the penetration of basic telecommunication services to the inhabiting communities. In this context, decrees of laws and regulations were defined in 2004 and 2006, respectively, in which all entities licensed or registered in the scope of the activity of providing public telecommunications services contribute to the FSAU with up to 1%. Between 2008 and 2015, FSAU benefited more than 1,238,300 inhabitants in 97 localities of the country [106].

5.6.1 The telecommunication sector

The telecommunication sector has undergone a historical evolution since 1981 with the creation of the state-owned company *Telecomunicações de Moçambique* (TDM) resulting from the decentralization of services: postal services, telegraphs and telephones (CTT). The Telecommunications Law introduced in 1992 resulted in the creation of the National Institute of Communications of Mozambique (*Instituto Nacional de Comunicações de Moçambique* - INCM) as the regulator, supervisory and manager of the radio frequency spectrum, under the supervision of the Ministry of Transport and Communications. In 1997, the first mobile cellular telephone operator Moçambique Celular (mCel), based on Global System Mobile (GSM) technology, was launched, under a public/private consortium owned by the state and TDM. However, in 2003 the need to separate the assets between the fixed and mobile networks formerly held by TDM, gave to mCel the administrative, financial and equity autonomy. Currently, Moçambique Telecom (TMcel) is the new state-owned company resulting from the merger of the state telecommunications operators mcel and TDM, announced in 2016, as part of the restructuring of the corporate public sector.

Still, in 2003, Vodacom Mozambique (VM), a consortium led by the South African company Vodacom

International, became the second mobile operator in the country, opening up space for competition and strengthening the regulatory framework of the communications sector in the country. The 3rd mobile operator Movitel, SA, started operating in 2012 as result of a partnership between ViettelGroup (Vietnamese) and SPI Sociedade de Gestão e Investimentos, SARL (Mozambican)[106].

Movitel has rapidly implemented its telecommunication network in rural areas, covering the population of the districts and administrative posts that did not yet benefit from mobile cellular services, which encouraged other operators, mCel and VM, to increase the investment in these areas. The Universal Access fund also contributed to the expansion of the telecommunications network in rural areas. Under this framework, the mobile telephony service reached in 2015 a global penetration of 78.24% of the population in the country.

Regional and international infrastructure

Regarding the regional and international infrastructure, Mozambique has transmission links (fiber optic and radio) with South Africa, Swaziland and Zimbabwe, and with Malawi (fiber optic). In more detail: SEACOM is a company involving mostly African shareholders and some telecommunications operators, operating a fiber optic submarine cable network along the eastern coast of Africa; Eassy is a consortium involving a group of African and international shareholders, operators and telecommunications service providers, who financed the deployment of a submarine fiber optic cable network along the eastern coast of Africa, being also an alternative to the flow of traffic from Zimbabwe, Malawi, Swaziland and Zambia.

MOZIX

Mozambique Internet eXchange point (MOZIX) is one of the initiatives included in the information technology policy of the Mozambican government. This initiative was implemented in 2002, beginning with a layer 2 network infrastructure with 5 ISPs. The main objectives of MOZIX are to improve the quality of the interconnection of existing IP networks in Mozambique and to avoid the use of international resources for the transit of IP packets to and from Mozambique, thus allowing cost reduction, better bandwidth management and latency. At present, the operational management of MOZIX, including electricity and human resources costs, are under the responsibility of the Informatics Center of UEM, operating with 16 ISPs.

5.6.2 MoRENet - Mozambique NREN

Communication costs in Mozambique are high, which is another factor that hinders the access of academic and research community to information and international cooperation. Service providers do not offer high-

speed connectivity and economically sustainable services to higher education and research institutions to support their activities. Due to the lack of financial means, most institutions had Internet service contracts ranging from 4Mbps to 12Mbps, capabilities that did not guarantee the provision of consistent services facing the current reality and demands of multiservice networks.

In 2006, aiming at strengthening the National System of Science, Technology and Innovation, the then MST started a project for the development of Mozambique's NREN, called MoRENet. Its implementation began in 2008, due to the MST need for acquisition of external financing, having been carried out at different stages. In this sense, in MoRENet development, two important periods until the current phase can be considered, according to the technologies offered by the market: the pilot phase, with a wireless-based technology infrastructure, and the current phase, based on fiber-optic, as described in Table 7. The implementation based on fiber-optic technology, began in 2012, aiming at interconnecting around 83 sites from higher education and research institutions using 34 Mbps links and a shared Internet access of 155Mbps through SEACOM, the submarine fiber-optic cable operator providing international access. At that time, the project was focused on Maputo, the capital of the country, connecting only 13 institutions in the region.

Given this perspective, an enormous effort by stakeholders was carried out, to ensure that the project becomes a reality, although several difficulties in the agreement settled with the operator responsible for MoRENet implementation were detected, namely:

- the lack of terminal equipment in the Mozambican market which must be imported causing significant delays;
- the lack of a metropolitan optical fiber infrastructure;
- the project was estimated for a period of three months but the provider took a period of 6 months to 1 year just to install fiber in 13 institutions.
- power outages, common in the country, undermine the proper functioning of MoRENet, which implies the creation of contingency plans for infrastructures and natural disasters.

Considering the difficulties presented above, the MoRENet project managers looked for alternatives to solve the problems related to the installation of optical fiber in institutions, changing the service provider. The new milestones aimed to cover in 2015 all the institutions on Maputo and then to include the institutions in provinces till 2016.

MoRENet network infrastructure has evinced an enormous evolution to be fully operational (at connectivity level and access bandwidth capacity), according to the objectives established between 2012 and 2015

Description	MoRENet: Pilot Phase	MoRENet: Optical Fiber Phase
Start date	2008	2012
Finish date (prediction)	2008	2014
Technology	Wireless - Wimax	Optical fiber: SDH-STM; 155 Mbps for backbone; 5 PoPs; 34 Mbps for institutions; 155 Mbps shared Internet connection.
Coverage area	Maputo city - 10Km square	All the country
# Institutions	9-10	82
Results	The network was setup; the network did not work in conditions; the installed antennas were burned due to electric power problems; the network performance and QoS was not measured because it failed to meet the goals.	The network has been installed but only in Maputo; only 13 institutions of Maputo city were connect; services provided: only Internet. In 2015: new contract with a new communications service provider; connect the institutions of Maputo, and then gradually contemplate the provinces. In 2022: $\sim$ 160 institutions interconnected.

Table 7: MoRENet phases

to cover all member institutions. In terms of access bandwidth capacity, a new service agreement with another operator was established (Movitel), to be able to respond to the need for expansion of MoRENet to 85 sites/campus of higher education and research across the country. Movitel's total operating costs was 25% less than TDM, providing 20Mbps or 100Mbps links depending on the dimension of the campus. Currently, the national backbone infrastructure links to the TDM and Movitel (to allow redundancy), with the capacity and characteristics presented in Table 8, having 6 PoPs, 2 in Maputo (MCTES and Empresa Parque Nacional de Ciência e Tecnologia - EPNCT, in Maluana), and 4 in the following capital of province: Beira, Tete, Nampula and Niassa.

In addition, regarding national and international traffic, the following links exist: (i) National Traffic: MCTES - MOZIX (100 Mbps); (ii) International Traffic: EPNCT - UbuntuNet London (500 Mbps) and MCTES - UbuntuNet (SEACOM) (500Mbps).

5.6.3 Providing sustainable services to MoRENet community

Currently, MoRENet project is associated with MCTES, which guarantees its operation until MoRENet can perform autonomously. In order to facilitate activities related to the promotion of science and technology, MoRENet is operating at the facilities of Maluana National Science and Technology Park. This new technology center is located 60 km from the capital, being created to promote activities related to innovation and development in Mozambique, involving resources such as hatcheries, laboratories, spaces for hosting startups and conferences.

Although MoRENet network infrastructure has undergone a significant evolution in the capacity of the national backbone and access networks, and in the number of connected institutions, Internet connectivity is still provided in a fixed way for the majority of users. In addition, the provision of advanced services to foster education and science is still scarce. In this way, the challenges of supporting three crucial services in a NREN service model are discussed below.

Wireless access (eduroam)

To foster the evolution of the network to an infrastructure that facilitates users' mobility, MoRENet has started with the education roaming (eduroam) network project. Eduroam offers a mobility service that allows students, teachers, researchers and institutional collaborators secure access to the internet through their institutional login in any entity participating in eduroam. Currently, it covers 16 campuses located in the following provinces: 9 in Maputo; 3 in Sofala; 1 in Zambézia; 2 in Nampula; and 1 in Inhambane. The idea of including a wireless network service arose because HEI already linked to MoRENet could not provide

#	PoPs	# Access Connections	National Backbone	
			Location	Bandwidth (Mbps)
1	MCTESTP	52	ENPCT	200
			Beira	500
			Nampula	500
2	Maluana (ENPCT)	6	MCTESTP	200
			Beira	500
			Nampula	500
3	Beira	7	Tete	200
			Nampula	200
			ENPCT	500
			MCTESTP	500
4	Tete	5	Niassa	200
			Beira	200
5	Nampula	11	Lichinga	200
			Beira	200
6	Lichinga	2	Nampula	200
			Tete	200

Table 8: MoRENet infrastructure

connectivity to a reasonable number of users, as the access to Internet was only possible in computer rooms. Eduroam project, although not covering most of the academic and scientific community, has been possible due to the technical cooperation established with RNP, the NREN of Brasil, which provided: (i) training in information technology; (ii) exchange of good practices in management and governance of research networks; and (iii) exchange of information on technical and operational management.

e-Learning

Regarding e-learning in the scope of MoRENet, it is clear that this service should be included in the provided services to member institutions. As an example, considering the case study of the Portuguese NREN initiative Educast@fccn, the use of Podcast platforms should improve the quality of distance education,

promoting the publication of audio and video content and their download, as a way to motivate the academic community to take advantage of this facility. Podcast can be used to record classes, seminars, material lectures in the courses, academic and scientific events that are published on the web for later use of the community of scientific and research content.

To successfully implement a podcast service in an NREN, the quality/capacity of the Internet services, specially wireless connectivity, is an important factor to take into account. Other factor includes the support of technical staff and audio-visual equipment for the recording of multimedia educational content on the platform.

OA repositories

- Repositories are another example of a service that can be provided by NRENs to promote electronic access and visibility to the scientific production of a country. The UEM initiative to create the national repository SABER in 2009 opened space for Mozambique to be a part of OA, creating an opportunity to enlarge visibility and preserve national academic and scientific production. However, the common repository project to integrate Mozambican institutions has failed. According to the study conducted in [9], the main factors that undermine the sustainability of the SABER repository were: (i) the lack of governmental and institutional OA policies and mandates; (ii) low disclosure and lack of promotion plans on the benefits of OA; and (iii) the difficulty of producing original content in the country. Considering this framework, as in the Portuguese NREN, a service model involving a national OA repository that aggregates the institutional repositories hosted and technically supported by MoRENet may prove to be an asset in the sharing and access to scientific content, involving academic and research institutions into a common OA repository. In this way, the discussion and articulation of technological aspects in terms of communications and services infrastructures, organizational and governmental issues for OA support, and financing aspects for supporting the access to scientific literature, become essential to foster the scientific development of the country.

5.7 Summary

This chapter has discussed important vectors involved in the development of scientific research and education in Mozambique. The study focused on the higher education framing, the implementation of OA initiatives and e-learning strategies, and the technological challenges involved in the evolution of MoRENet. These are considered important aspects for promoting knowledge growth and for training human qualified

resources in the country. From the analysis carried out, became evident that technological infrastructures and services, and regulation initiatives are crucial factors for success. Nevertheless, several aspects of the country's reality impair achieving their full benefit. This represents a main motivation for the multidimensional model for fostering science and education in Mozambique presented in the following chapter.

Chapter 6

Proposed Model for Open Science in Mozambique

In this chapter, a model integrating the main components for science growth in Mozambique is presented, focusing on the contexts of higher education, open science, science management, distance learning, and technological infrastructures supporting science and education. This model is framed by an encompassing discussion on challenges and recommendations in the areas debated in previous chapters, in particular OA issues and advanced services supported by NRENs (MoRENet), and aspects related to the problems in the higher education system, the difficulty of accessing and managing scientific information, and the challenges for successful e-learning initiatives. This proposed model, centered on the multiple interrelated vectors, is presented below, followed by a step-by-step discussion of each aspect in the remaining sections.

6.1 Science growth interrelated vectors

The main challenges for scientific development in Mozambique are leadership and political will, and funding for science and research, which largely comes from abroad. Science continues to be practiced by a very small elite, which is why it is necessary to stimulate public debate on science in developing countries, so that the population understands the relationship between scientific themes and their daily lives.

Since July 2003, Mozambique has had a science and technology policy. This is a basic, transversal policy, with the main objective of stimulating national innovation for the benefit of development and the fight against poverty. The Mozambican science and technology policy is based on four pillars: education, research, productive activities and dissemination. It is through strengthening the internal capacity of each of these pillars, as well as improving communication between them, that the policy seeks to promote the desired national innovation, resorting, on the one hand, to existing resources within the country and, on the other, to scientific knowledge and technologies developed abroad.

The formulation of science and technology policy is justified by the change taking place in the economic organization at a global level. Currently, a country's ability to create wealth depends less on its natural

resources, and more on its ability to transform resources into production and consumption goods, and services. It is within this transformation that science and technology play a pivotal role. In fact, the value of most goods depends mainly on the science and technology incorporated in them. Thus, for Mozambique not to be marginalized in a global knowledge society, it is necessary to strategically invest in its scientific and technological capacities.

Considering the role of higher education and scientific research in this panorama, promoting science growth is deeply related to accessing knowledge. The access to academic and scientific literature through digital libraries and open access repositories involves the storage of data in information systems and their access via NRENs. NRENs, providing either application and operational support services, represent the current trend of collaboration and sharing of scientific knowledge among the various communities spread throughout the world, with emphasis on HEIs, libraries, schools and, in some cases, government institutions. In this panorama for science growth, facing Mozambique's difficulties in a global system of high-quality face-to-face education, e-learning technologies and initiatives became mandatory. At a higher education level, these initiatives, involving worldwide partnerships with developed countries, represent many times the convenient way to sustain international curricula and research projects, crucial to guide the country to the next level from an education and research perspective.

In this context, Figure 16 illustrates these interrelated vectors, each one organized and discussed in a specific section below, to help clarify existing barriers and future concerns to address for fostering the sustainable evolution of the Mozambique science and education ecosystem. The next chapter (Chapter 7) will reinforce the challenges and next steps for the proposed vision, presenting an organization centered in Africa, globally, and Mozambique, especially.

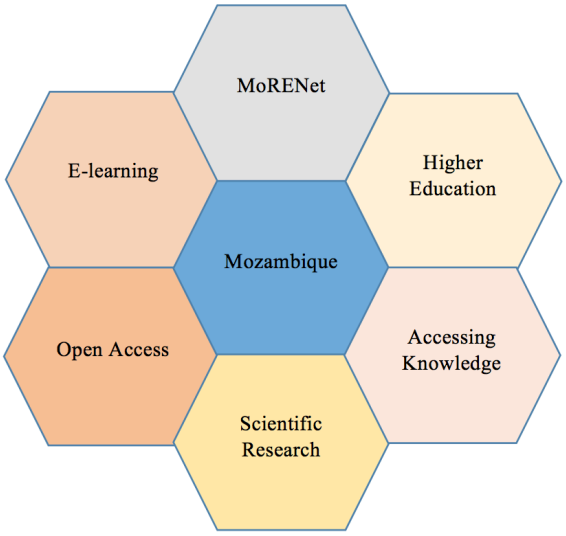


Figure 16: Vectors of the Open Science model

6.2 Higher Education

The expansion of universities in Mozambique sought to respond to the demand for education by the growing number of students who finish secondary education, who want and can continue their studies. The Mozambican State did not prepare itself for the rapid increase in the influx of students to higher education, having not created new universities, and courses and prepared scientific and pedagogical conditions for diversification of supply (types of courses) and elevation of teaching degrees (masters and doctorates). The deficit in the supply of public education was being overcome with the emergence and development of private universities, without there being trained teachers for the growth of students and universities. The investments focused on installations, and libraries, laboratories, teaching equipment, organization and training in university management were not prioritized.

In 2019, Mozambican higher education had 212,600 students, distributed across nearly 50 public and private institutions, with about 800 courses to be given. Mozambican higher education hosts 6% of students who finish secondary and the government intends to increase the number of students, as this percentage of entry into higher education is one of the worst in southern Africa, and shows that there is room for more institutions, especially private ones. For instance, in South Africa, Mozambique's neighboring country, 22% of students who finish secondary school enter higher education. However, it is necessary to look at the quality of institutions, demanding that they respect universal criteria. For this purpose, for the first time, the country has an inspection commission of higher education institutions. In just the first year of activity, the commission has already banned 12 units of higher establishments for lack of permits.

The significant growth, both in higher education institutions and the universe of students covered by them, has posed enormous challenges to the functionality of the subsystem and to the quality of its teaching in Mozambique. The growing recognition of the importance of universities for the social and economic development of states and communities has raised a number of questions about how the benefits and impact of these institutions can be properly channeled and optimized. These concerns stem both from the emerging awareness of the role of universities themselves in society, and also as a consequence of extrinsic market forces and government intervention, both deeply influenced by global economic imperatives. Mozambican universities cannot be detached from the processes and dynamics of higher education on a global scale. They have been influenced by curricular reforms that have taken place in other parts of the world, where the regional integration process in Southern Africa and the Bologna Process stand out.

Facing this panorama, several barriers and weaknesses for the improvement of Mozambique's higher education system have been identified, and need to be overcome, namely:

- not all higher education institutions in Mozambique have sufficient human resources, in quantity and quality, in their management structure (particularly private institutions). Public institutions also have their rectors or directors appointed by the political power, compromising their internal democracy;

- the scarcity of specialized human resources, the lack of inspection and assessment actions by higher education institutions, and the poor compliance with the legislation that regulates them, in addition to the feeling of trivialization of higher education, have been highlighted as some of its most serious constraints;

- one main criticism that has also been made of Mozambican higher education has to do with the uncontrolled proliferation of higher education institutions, with a significant inclination towards the social and human sciences rather than technical areas, with the generalized indicators of low quality of its graduates, with the almost non-existent component of research and university extension and, finally, with its weak or non-existent competitiveness at the international level;

- all higher education institutions, both private and public, are dedicated almost exclusively to teaching (predominantly in undergraduate courses), leaving research and university extension to a secondary level. As mentioned, the vast majority of courses taught in Mozambican higher education, both public and private, are in the area of social and human sciences, to the detriment of polytechnic areas. This imbalance should be a challenge to be resolved in the future;

- one of the main constraints arising from the massification efforts of higher education in Mozambique is the physical and technological infrastructure. There are higher education institutions that do not have their own facilities, suitable for teaching, research, accommodation, and leisure activities. The low level of investment in pedagogical support services (libraries, laboratories, and technological resources), social (student residences and canteens), cultural (amphitheaters), and sports results in an impairment that needs to be overcome.

These weaknesses negatively influence the quality of teaching and learning, especially in courses that depend heavily on the availability of libraries with up-to-date collections, equipped laboratories, appropriate physical spaces, and the existence of technological resources (especially computer material and Internet access).

6.3 Accessing knowledge

In developing countries as Mozambique, the access to information and communication technologies is considered crucial to promoting development and integration into a knowledge society. Human capital must also be considered as a source of sustainable development and social inclusion to create appropriate solutions according to the challenges of the science and education ecosystem of each country. Therefore, in these countries, e-learning is presently considered a key solution to promote global access to knowledge, fight illiteracy and increase the access to higher education. Several specific programs and e-learning initiatives have been encouraged, having however scarce results so far [11]. NRENs are major promoters of the involvement of the academic and scientific community in the use of new services and applications oriented to support and improve their activities.

In developing countries, where the access to information and the sharing of knowledge are still scarce, especially in rural areas, the use of supporting platforms for distance education are a convenient alternative to promote science and education. Thus, in [13] it is proposed that African NRENs put e-learning and OA services in the frontline, combined with national research programs and international cooperation, as these are important steps for enlarging the impact of these initiatives and fostering the developing of African countries scientifically and socially. Being part of the main vectors of the proposed Open Science model, these aspects are conveniently addressed in Sections 6.5 and 6.6, and in Chapter 7.

The acquisition model of scientific literature through commercial publishers in Mozambique is not associated with the academy of sciences of the country. In this sense UEM is the national coordinator of the consortium of universities supported by the INASP project, being responsible for channeling the budget available for paying the access to publications for the institutions of higher education (public and private) in the country. With INASP support, Mozambique can access 90% of the publications paying 10% of their real value. However, the utilization rates are very low, ranging between 5-10% of downloads per year to about 23,000 titles, with a cost of 30,000 dollars annually. Given the low level of downloads of publications, it is important to: (i) promote online access to the main sources of international knowledge; (ii) encourage the global electronic subscription allowing access through centralized trading; (iii) stimulate the community to use and produce scientific content; (iv) rationalize costs and resources, a factor that allows avoiding duplication and getting more publications for less money; (v) continue with a community need analysis and consolidate the project; (vi) work at the dissemination level to increase the use of available resources.

UEM started in 2015 with the establishment of a consortium of HEIs and research libraries, but this initiative is still in the phase of registering institutions. Note that, there are other organizations with pro-

grams supporting access to scientific literature from specific areas that Mozambique and other developing countries use, namely HINARI, for biomedical, OARE, in the environmental field and AGORA for agriculture.

6.4 Scientific research

Scientific research in Mozambique is still in its infancy. After independence in 1975, the number of trained teachers was insufficient to cover the needs of education and higher education in the country, and not keep pace with population growth. The civil conflict between 1977 and 1992 had a negative influence on the country's growth. Before independence, the training of most Mozambican citizens was minimal or nil and the UEM curriculum reform that occurred at that time included new curricula and Bachelor's degree courses, to respond quickly to the needs of the labor market. Currently, Mozambique has nearly 50 higher education institutions, however, in the world ranking, Mozambican universities are in a low place, being UEM considered the best higher education institution in the country. In this sense, the framework for the development of an information society in the country, the ICT policy adopted in 2000, has defined main objectives to combat poverty and improve Mozambican lives. To ensure the production and access to knowledge are some of the fundamental aspects of the ICT policy for Mozambique to become a relevant and competitive partner in the global information society [9].

In 2005 was created the NRF, the main government agency responsible for funding research in Mozambique. The promotion of programs, projects and actions in the field of scientific research in accordance with the strategic priorities of the country are the main objectives of the NRF. From the NRF budget to support research projects, mainly resulting from external support, a large part of the investment is dedicated to the training of human resources. From the discussion above, several points regarding the evolution of OA and MoRENet can be stressed. Currently, the lack of governmental and institutional OA policies, skilled human resources, network infrastructures and equipments, and the country financial dependence are viewed as the main obstacles to promoting OA mentality and reality in the country. These aspects are further debated in the sections below.

6.5 Open Access

Currently, economic growth is the central concern of Mozambique, especially for the government and entrepreneurs, and the lack of a skilled national workforce is a gap that must be solved. In the current context of evolution of networks and communication services, Mozambique is not included in the top list of African countries using Internet. Thus, the Mozambican government has set up several strategies

for the country's technological development, being the Science, Technology and Innovation Strategy of Mozambique (STISM) one of the most relevant [7].

The OA movement in Mozambique is recent, mostly driven by UEM initiatives that try to give visibility and preserve the academic and scientific production of national institutions. SABER repository, the common platform that integrates officially six member institutions, maintains scientific and academic documents produced or related to Mozambique from distinct institutions in the country. In 2019, SABER became unavailable. Taking into account these aspects and the absence of national and institutional policies, it is therefore important to understand and respond against existing barriers that limit the success of OA in Mozambique.

Considering this framing, in Section 6.5.1 is proposed the initial deployment of the Mozambican OA service model on MoRENet. One of the services suggested is a common OA repository hosted and technically supported by MoRENet that would allow concentrating financial and technical efforts while enrolling the Mozambican academic and research institutions into an OA national objective. Facing the reduced scientific production in developing countries, the inclusion of a large number of institutions into a common repository may represent a new beginning in the perception of OA benefits. Considering the size of the scientific and academic production of each Mozambican institution and the creation of institutional repositories, this common repository may evolve afterward into a meta-repository, accommodating institutional repositories.

The reactivation and evolution of SABER into a multi-institutional repository representing the national identity, offering a hosting service of repositories in the cloud, will reduce operational OA costs while preserving the image of the institutions under a common service. To attain this level of evolution, the establishment of a task force and specific projects aiming to foster the implementation of SABER at a national scale may be necessary. The international cooperation would provide the experience of other countries and international projects on OA policies, including the understanding of technical aspects of knowledge management. This vision for the evolution of SABER and MoRENet will also bring a new dimension for the Mozambican NREN, regarding the provision of advanced services to the academic and research community [9].

Regarding SABER repository, based on the data presented in Section 5.3, it appears that not all adherent institutions contribute effectively for its growth, providing results of their academic and scientific activities. UEM is the most effective contributor to the initiative of information access free and without restrictions. Regarding the OA journal RC-UEM, the lack of contents has been one of the largest barriers to its launch on a regular basis [107]. In addition, although Mozambican higher education institutions have

available electronic access to international magazines, their usage remains below the expectations of the documentation services responsible for the access. Looking for answers about the barriers that limit the success of OA in Mozambique, according to the information collected from face-to-face interviews in UEM and MoRENet, through publications devoted to the development of science, technology and innovation in Mozambique, and to the release of OA, the following main barriers were identified:

- socio-cultural: resistance to change and to new behaviors related to Internet use. The academic and scientific community should be informed where and how to find information and develop a culture of sharing and disseminating knowledge;
- economic: many institutions and their communities are not sufficiently equipped with resources that facilitate the access and storage of information;
- technological: the quality of the access to information is precarious due to low speed of network connections and the constant power outage;
- intellectual property protection: to boost the intellectual property system in the country, in 2008 the STM launched the "Intellectual Property Strategy" document approved by the government, as an instrument to serve the interests of the economic, social, technological, scientific and cultural development of the country. Its implementation lacks a legal system and has not yet enshrined the national rights of intellectual property defending authors;
- scientific community: the research level is still low and the few researchers are in most cases bound to international research institutions. Therefore, most of publications go out of the country, which constitutes an obstacle to nationwide scientific production.

In this context, it is necessary to take more information actions, disclosing the existence of specific services that provide access to information, publishing the portals and how to use them. Nationally, there are no governmental and institutional policies of OA, therefore it is necessary to raise awareness among government institutions and funding agencies of OA initiatives. The effective implementation of MoRENet can contribute not only to supplying high-speed connectivity as well as a valuable partner in providing services for free access to knowledge.

6.5.1 Proposed Open Science services

Considering the challenges that Mozambican institutions face in implementing national and institutional policies and mandates of OA, this section presents the proposal of an initial model for open science

services in Mozambique. This model, presented in Figure 17, inspired by the model of the Portuguese national initiative RCAAP [5, 3, 7], takes advantage of the benefits of a supporting NREN to propose the creation of the following services:

- the Hosting Repository Service for all institutions, so that they do not have to worry about the technical aspects related to the implementation of repositories, such as servers, connectivity, maintenance, backups, upgrades, monitoring, and alarms. The national repository of Mozambique SABER should provide centrally the tasks related to the management and operation of repositories, and the member institutions only have to worry about the management of their documents (workflow and deposit);

- the Common Repository, oriented to institutions that do not have their own repositories, for various reasons, such as the low number of publications. Excluding UEM, the five other institutions integrated into SABER repository could benefit from this service. This alternative will allow researchers and the academic community of these institutions to have a shared repository for depositing in OA the results of their work. An institution taking part in a common repository may in the future evolve to its own hosted repository, when an increase of documents resulting from academic and scientific production occurs;

- a Hosting Service of Scientific Journals should be considered, such as the RC-UEM, which institutions may use to create a journal and make the whole lifecycle, namely the launch of calls for submission of articles, the support of peer reviewing, the editing and processing of scientific data;

- facing the issue of curation and preservation of scientific data, aligned with the recent guidelines on OA, it is important to include one Scientific Data Hosting Service, so that data that led to the publication of articles can be consulted and reused;

- another aspect to consider, taking the example of the Portuguese national repository initiative to strengthen the visibility of OA scientific contents of Portuguese language, is the signing of a memorandum of understanding between the governments of Portugal and Brazil, which resulted in the aggregation of theses and Brazilian scientific production and dissertations available in Brazilian institutional repositories. Subsequently, it was also created the Luso-Brazilian Conference on OA (ConfOA) held annually and open to all interested in sharing knowledge and experiences.

Considering that there is much work to do for the proposed model to be successful, the following challenges and recommendations should be considered:

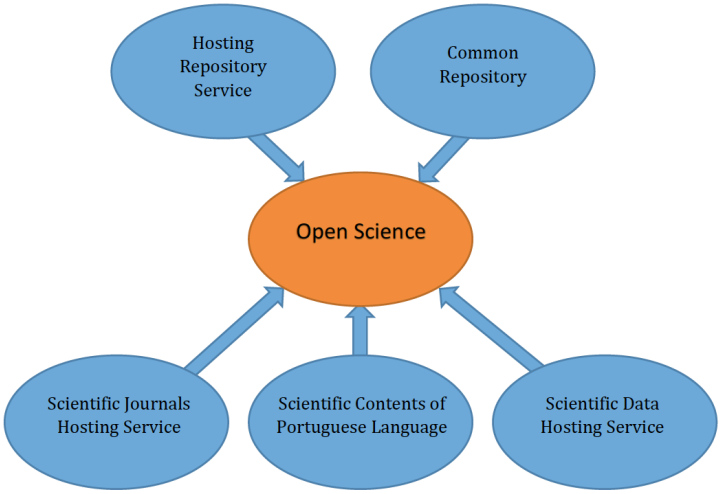


Figure 17: Open Science services in Mozambique

- the guidelines of the ministry of science and technology are not specific in terms of repositories and OA, just pointing out the need for the dissemination of scientific knowledge. In this sense, it is important that higher education institutions, through the Rectors Council of the country, the Academy of Sciences, the Ministry of Science and Technology entities and MoRENet, to engage in the debate about OA to involve a larger number of institutions into SABER repository;

- most of university libraries do not have a librarian. The country must invest in training librarians and specially trained staff to support the academic community and to manage contents;

- it should be created a national team for dissemination and training on OA, operating in the institutions in collaboration with other regional and international institutions, including the UbuntuNet Alliance which ensures effective implementation of OA in Mozambique;

- the collaboration at CPLP level on the issue of OA should also be considered. The team of UEM documentation services has participated in ConfOA, and has made efforts to become a membership. This has proved to be complicated by the need to establish memorandums of understanding between the governments. The FCT in Portugal showed interest in starting the initial collaboration through the organization of a workshop in Mozambique in 2016 aimed at training and debating the various issues related to OA and managing science. This first seminar on OA took place in Maputo, at UEM, on May 2016;

- the NRF needs to create a database of researchers with unique identifiers, since this entity is responsible for financing research in Mozambique. It should also be rethought the most appropriate way to implement a management system of the curricula of researchers who may undergo an

effective collaboration with institutions linked to similar projects, such as Lattes of Brazil and DeGóis in Portugal, for sharing experiences;

- in the context of UbuntuNet Alliance and African Union, it is important to rethink effectively and comprehensively about creating a regional platform that can support researchers and research results funded by their supported programs and projects, hosting not only documents in full-text format but also the research data set. South Africa, being the country with the highest number of OA repositories, is also the only country that has implemented a data repository, the South African Data Archive (SADA) [108]. These aspects underscore the need for sharing experiences among African countries that are at the forefront of the issue of OA, such as South Africa and Kenya.

6.6 e-Learning and Podcast

The implementation and application of e-learning are still taking the first steps in African countries. Despite the shortage of resources, infrastructures and access to information, many African countries have shown an interest in implementing e-learning to foster scientific and social development. This has led to the definition of national and African Union projects and strategies in the e-learning context [109].

The integration of technological platforms for education in these countries faces enormous challenges due to cultural, political and economic factors. It is in this sense that it is important to consider e-learning strategies and, in particular, the use of audio and video-based applications to support the training of a large number of students with economic difficulties and short access to ICTs. This main concern differs from the concern of the more developed countries which is the development of the knowledge society.

This motivates the need to define successful strategies for e-learning in African countries, taking into account the national challenges and the higher education ecosystem, so that e-learning may reveal to be a success factor for education and science. As discussed, taking the cases presented in African countries, and especially the projects implemented in Mozambique, they lack a more comprehensive view of the implementation of e-learning. The problems identified reveal the need to create a common platform that benefits the entire academic and scientific community, with MoRENet as primarily responsible for promoting the production, distribution and consumption of educational, cultural or entertainment content in a national audiovisual format. Similarly to the educast@fccn service provided by the Portuguese NREN, podcast as a service supported by MoRENet can be viewed as a comprehensive alternative to e-learning in Mozambique, enrolling and supporting multiple higher education institutions in a large-scale vision and deployment of e-learning.

Despite the evident potential of this e-learning strategy, the main critical success factors to the implementation of a podcast platform in Mozambique should be carefully considered, in particular:

- clear definition of policies and strategies at the national level;
- appropriate technological support, regarding the network capacity, the existing resources and the location of the service;
- acquisition or implementation of the service, being the dissemination and marketing of the podcast and training of teachers and students important factors;
- collaboration and international cooperation in terms of technical and technological management;
- identification and acquisition of the recording equipment and creation of the technical team that responds to the needs of the participating institutions.

6.7 MoRENet

MoRENet implementation began in 2008, due to the Ministry of Science and Technology (MST) need for acquisition of external financing, having been carried out in different stages. Despite the difficulties and challenges faced by MoRENet, its effective implementation was thanks to the effort, appropriate measures and political decisions, that allowed it to become a reality. The proper allocation of financial resources and the creation of an environment that would enable the participation of key stakeholders in an initiative such as MoRENet contributed to its success.

Currently, MoRENet is operational and interconnects 160 research and education institutions around the country. The MoRENet Conference is an event held annually that aims to serve as a platform for debate between the different participants, regarding the value and services of MoRENet for the academic and scientific communities, the dissemination and use of services by members of beneficiary institutions, the innovation and creativity to address the challenges of using technologies by members of the academic and scientific communities in Mozambique.

Despite this, there remains the challenge of making an analysis of MoRENet service quality levels, ensuring that institutions already connected may discard existing contracts with commercial operators, to ensure the reduction of investment costs previously held by them. Other main challenges regarding MoRENet include:

- the need to institutionalize MoRENet and to define an economic sustainability model. This will allow to increase autonomy, for instance, to hire more skilled human resources for its deployment;

- the implementation of new services on the network to promote the information exchange between national and international scientific communities. As mentioned, in the future, to sustain science growth, it will be necessary for MoRENet to provide other types of services beyond connectivity and Internet access;

- the need for increasing the Internet access bandwidth and the national/international connectivity [7]. The increase in the number of beneficiary institutions and in the number of MoRENet users will imply to increase the network's capacity in terms of national and international connections;

- regarding service quality, it is necessary to create technical teams in the institutions (e.g., Communications Services in HEIs) that work directly with MoRENet in solving network problems, while promoting the evolution and the creation of new services to the enrolled community.

6.8 Summary

The research and lessons learned from worldwide initiatives and case studies related to science support, access and growth, in developed and developing countries, have culminated in the proposal of this chapter.

In this way, this chapter has presented a model integrating the main vectors to consider for fostering science in Mozambique, focusing on higher education, open science, science management, distance learning, and technological infrastructures supporting science and education. These vectors were discussed step by step, giving particular attention to: the role of OA, where an open science model for Mozambique has been proposed; distance learning, as the convenient approach to enlarge the geographical scope of higher education and science, and to promote international collaboration; and the role of NRENs as the supporting communication and services infrastructure.

Chapter 7

Challenges and Next Steps

This chapter presents an encompassing discussion of identified challenges and next steps towards the deployment, evolution and sustainability of the distinct vectors comprised in the model for science growth presented in the previous chapter. The discussion is firstly oriented at the African level and, then, refined at the Mozambique level.

7.1 Africa

Technological advances seen in recent decades have enabled a high level of visibility to academic and research institutions. The main objective of the OA movement is to encourage reading and obtaining knowledge for all. In addition, it seeks to stimulate dialogue between scientists in a faster and more effective way, once everyone has access to publications. Many journals are already adhering to this idea, making their publications open to any audience. Thus, in the current scenario of increasingly agile online publications, it is necessary to understand that the more obstacles there are in accessing a journal, the more restricted the dialogue promoting science.

Currently, open access to scientific literature has increasingly become the basis of academic communication around the world. Contrary to this trend, many African countries fail to achieve this goal for various reasons, such as the lack of OA platforms, lack of awareness and willingness to publish their work in OA. Despite the existing challenges in the implementation of repositories, the general panorama of scientific research is promising considering the ethnic and cultural diversity and the abundance of natural resources, if the following problems of the post-colonial era are solved: poverty; political instability; corruption; diseases and armed conflicts that hamper the continent's development.

Open Access issues

Facing the mentioned aspects, it is crucial to take consciousness of the major impairments for the growth of the distinct OA perspectives in Africa, and rapidly to contradict them. In particular:

- to encourage the practice of self-archiving, it is essential to define OA policies on two fronts: institutional and national levels. Scientific production financed with public funds needs to be deposited in the appropriate repository, supported with national and institutional mandates and policies, as a way of giving greater visibility and use to the results of the research carried out;

- regarding OA policies and mandates in Africa registered in ROARMAP, there are only 35 registered institutions associated with 8 countries, namely Kenya (15), South Africa (11), Algeria (3), Zimbabwe (2), Burundi (1), Ghana (1), Nigeria (1) and Tanzania (1). These data demonstrate the need to analyze the challenges and barriers that impede the implementation of national and institutional OA mandates and policies. It is necessary for African governments to create programs that promote scientific research and encourage OA. In this context, the OA movement in Africa can only be successful if it benefits from better or greater involvement of educational and political decision-making bodies;

- the interest of developing countries in investing in technological infrastructures and science management platforms is remarkable and it is necessary to promote the unrestricted availability of scientific content to higher education and research institutions, as is already the case in developed countries. In particular, it is necessary that there are directives in the scientific ecosystems of developing countries that can support CRIS, which is a new paradigm that allows managing the various components and scientific players;

- another aspect to take into account is that higher education and research institutions in Africa lack financial resources, therefore, it is important that they adopt the existing open source technological alternatives for the creation of scientific repositories and forms of integration and interoperability with CRIS systems; In this sense, it is important to consider that repository-building platforms can be open source such as Dspace and ePrint, while existing CRIS are based on proprietary systems. This aspect makes it difficult to implement CRIS platforms in African countries;

- in terms of OA to research data, Africa has only one repository of this nature, the SADA. It is necessary for African countries to invest in the creation of data repositories resulting from scientific research carried out;

- it is necessary the existence of technological infrastructures with computational capacity that allows organizing this level of data in public or private databases, and with the ability to retrieve, recombine and process, so that they can finally be accessed and reused. The management, access and reuse of research data, and in particular research data financed with public funds, are themes that have acquired greater visibility over the years and attracted increased attention, both within the scientific community and in the sphere of politics at the international level;

- regarding journals, considered a main means of dissemination of science, the production of scientific OA journals in Africa is still scarce, with South Africa still leading. National and pan-African OA policies and collaboration between various actors in research and economic development will play a key role in the process of making science more visible inside and outside Africa;

- as mentioned in Chapter 4, currently the African continent has a total of 193 repositories belonging to only 25 of the 54 independent countries. Given these data, it is necessary for African countries to invest in broader strategies for the dissemination of open access to knowledge, promoting the creation of institutional repositories in universities and research centers as a way to give greater visibility and sharing knowledge of African scientific production.

e-Learning issues

Based on the results of the study conducted by [110], e-learning has enormous potential in Africa. Despite that, an adequate and fruitful use of e-learning requires knowledge. Therefore:

- institutions must raise the level of awareness, which involves promoting e-learning for its educators and students. It is necessary for the institution to provide ongoing training and support to students and educators so that they gain more confidence in the use of technology. For e-learning to be successful, educators must adopt e-learning after which students can implement it in their studies. Institutional support can be represented by a well-established e-learning department that is the face of the program, with an adequate number of staff members;

- although e-learning offers benefits for students in both urban and rural environments, these benefits are hampered due to inequality in terms of connectivity problems and technical difficulties, a deficient infrastructure, and high illiteracy rates on ICT, which promote insufficient e-learning. In practice, the main limiting factors include lack of computer literacy and training, lack of effectiveness, lack of awareness of technology and change, lack of economic development, and, finally, social and cultural differences.

These factors negatively influencing the adoption of e-learning [110], need to be step-by-step overcame.

NRENs issues

The main mission of an NREN is to represent and act on behalf of higher education and research institutions in providing information technology and communication services to connect these institutions both nationally and globally. These connections will provide NREN members with access to academic and scientific resources and support collaboration in teaching, learning and research. NRENs require specialized security and identity protocols, or sometimes very high bandwidth services, that are generally not available or are too expensive through an ISP. These specialized services are what largely justify the existence of an NREN [111].

While the Internet was expanding from academia to all parts of economic and social life in developed countries in the 1990s, Africa remained relatively isolated due to a lack of telecommunications infrastructure to support its acceptance and expansion. Most Internet access in Africa was through satellite systems that were extremely expensive and slow. The cost of bandwidth in Africa was approximately fifty times the cost of bandwidth in the United States and Europe. When undersea fiber optic cables finally reached African coasts in the last decades and terrestrial networks were rolled out to connect to them, there was a rapid growth in ISPs competing for market share in an evolving environment. Universities became an obvious market for them, being knowledge of NRENs scarce and generally confined to a small number of ICT staff at larger universities. In this way, on the African continent, the impetus for establishing NRENs was the arrival of submarine fiber optic cables along the east and west coasts and the result of the dramatic reduction in the cost of Internet access over the last decade. Bandwidth costs have dropped from typically $4,000-6,000 per megabit per second (Mbps) per month to less than $100 per Mbps per month in some countries as they switched from satellite technology to fiber-optic delivery. These developments were accompanied by efforts drawn from pioneering academics in some countries who, with the help of the Association of African Universities (AAU) and its REN unit, promoted an idea that African countries needed to establish their own NRENs and, eventually, linked up in a continental network through an initiative called the Research and Education in Africa Network (AfREN). In this sense, regional associations of NRENs have been formed to promote the AfREN concept, UbuntuNet Alliance in Eastern and Southern Africa, and WACREN in Western, Central Africa and, at the time, in the Middle East and North Africa formed an association of NRENs called ASREN. The European Union (EU) provided the financial means to kick-start this initiative by funding the AfricaConnect project. EU had already been funding a program to connect North African NRENs to Europe, the EUMEDCONNECT project [111]. The aim of these two

projects was to enable the emerging NRENs in the regions to establish linkages regionally and to connect to GÉANT, and through it to connect to all other NRENs of the world.

The few pioneers who were trying to establish NRENs had difficulty explaining the benefits of a dedicated NREN when most administrators thought was necessary commodity Internet services, and at the lowest price. It was just the price their main concern at a time when emerging NRENs didn't have resources and skills to offer services more sophisticated than simple Internet bandwidth. To raise awareness among decision-makers in government and academia of the potential benefits of NRENs and the need to build their capacity to harness the benefits that only they can offer, much work is being done by NREN advocates in Africa.

The emergence of NRENs in Africa shows strong growth, progressing with dynamic actors and consortia, but progress is slow in some countries. One of the biggest challenges for the NRENs is to persuade the leaders of the institutions and, in turn, their governments, of the need for a dedicated network that can respond to the special requirements of researchers, professors and students, and that this is a much more important and complex issue than simply providing Internet access. The lack of progress in such countries does not necessarily reflect a lack of interest among end-user stakeholders. Although financing, which must be continuous to be sustainable, is also a challenge, another challenge that NRENs face is the lack of awareness among decision-makers of how the Internet works and what added value an NREN can bring to higher education and research. The contribution that accessible resources through the Internet can contribute to improving the quality of education and skills development in African schools and higher education institutions must be demonstrated to educators and decision-makers in government.

Additional challenges in some African countries include the late arrival of fiber infrastructure, conservative attitudes within established telecommunications companies, and lack of regulation in the telecommunications sector. The aggressive competition itself from ISPs, who see NRENs as rivals for their customer base, is also worth mentioning.

At the beginning, for UbuntuNet Alliance, the challenges were also enormous: (i) a huge and diverse continent; (ii) limited competition in telecoms especially for international gateways; (iii) very little fiber reaching Africa at that time (just a SAT3 cable to South Africa); (iv) a scarcity of technical human capacity; (v) a lack of awareness on research networking in member countries; and (vi) extremely limited funding.

The africaConnect2 project, followed by africaConnect3, has enabled collaboration between higher education and research institutions in southern and eastern Africa. The main objective of these initiatives is to connect research institutions in the region, ensuring that there is a higher quality Internet with reduced costs, encouraging research. In addition to the construction of the network management infrastructure,

funding from the EU has helped to train the project's technicians and it is expected that, in the near future, a link will be established between all educational institutions in southern and eastern Africa, among public and private.

7.2 Mozambique

In May 2016, the Portuguese FCT and the NRF of Mozambique signed the first protocol for cooperation between the two countries in the areas of science, technology and innovation. This protocol has resulted from the need to develop joint scientific and technological relations, which will bring mutual benefits to both institutions and their countries. This agreement recognizes the importance of science, technology and innovation in promoting the growth and competitiveness of the national economy, therefore, FCT and NRF aim to promote cooperation in these fields on the basis of equality and mutual benefit. This memorandum of understanding intends to operationalize the following key areas of collaboration: exchange of staff, scientists, researchers and experts; exchange of scientific and technological information, teaching and learning materials resulting from cooperation; conduct joint activities, including scientific conferences, symposia, workshops and other meetings; support joint research and technological development projects; facilitate scientific exchange among research institutions; exchange of experience and expertise in information and communication technology for development; and promote the transfer of appropriate technology [112].

In a way, this memorandum represents the aim of Mozambique regarding education, science and research growth, by establishing partnerships with scientifically and technologically mature countries to share experiences and fulfill existing gaps. In more detail, the main weaknesses to address and the next steps toward their resolution include:

- lack of human and teaching resources: the lack of teachers in higher education at various levels compromises the efforts made to mass education. As an objective, it is necessary to train teaching staff and other professionals in specific areas for national development;

- language problems: the vast majority of scientific publications are in English, which constitutes a barrier to access to knowledge by all members of society. Many researchers tend to publish in English not only to interact with the international scientific community, but for a matter of status. Scientists who don't write in English don't have access to certain high-quality journals, that give them the legitimacy that allows them to enter the incentive system and to progress in scientific terms. However, the consequences of the fact that most science is produced and published in

English are also numerous: limited access to knowledge for hundreds of millions of Spanish and Portuguese speakers such as Mozambique citizens;

- lack of funds: projects that promote and benefit teaching and scientific research in Mozambique depend on support from the international community;
- lack of supporting facilities: some institutions are operating without libraries, laboratories, and other appropriate facilities for access to knowledge. HEIs must meet conditions that guarantee minimum standards of educational quality;
- digital illiteracy: it is necessary to improve digital literacy in the community. Higher education and research institutions must integrate ICT and Internet resources into their teaching, learning and research programs in a meaningful way, leading to the creation of a user base for the campus network and, in turn, the NREN and the international connectivity it provides;
- lack of libraries at country level: it is necessary to create a consortium of libraries in the country. With the emergence, diffusion and commercialization of electronic resources, the trend towards cooperation between libraries was reinforced. Libraries began to associate themselves in consortia in order to obtain better conditions in contract negotiations, and access to a larger number of titles, allowing smaller institutions to benefit from access to content (both in terms of quality and quantity) that otherwise they would hardly get funding for the transition from electronics and mutual technical support.

  For example, in Portugal the emergence of the b-on consortium took place in 2004, which may be recent when compared to other countries, however, the results are very encouraging, indicating the rapid receptivity and acceptance verified by the academic community and national scientific research. A consortium of libraries in Mozambique will allow it to increase its negotiating capacity, bring together the main publishers of international scientific journals in order to offer a wide range of scientific articles in full text, available online, among other resources. The Mozambique library consortium will aim to be a fundamental instrument of access to knowledge for the national academic and scientific community. As mentioned, the creation of a consortium of libraries will facilitate access to full-text articles from a relevant set of scientific publications, published by some of the most reputable publishers and holders of international scientific databases, exploiting economies of scale made possible by the purchase of centralized content. UEM started in 2015 with the establishment of a consortium of HEIs and research libraries, but this initiative is still in the phase of registering institutions.

- lack of librarians: it is necessary to train more librarians in Mozambique, information and content management professionals, whose primary role is to disseminate information. Librarians have an increasingly important role as a mediator of information, as they work in the most diverse areas of knowledge.

Open Access issues

At OA level, despite the numerous initiatives worldwide, there is a long road to run in Mozambique. Aspects to improve, include:

- OA scope: the OA movement in Mozambique has been mostly driven by UEM initiatives. It is necessary to broaden the OA movement from the UEM and expand to other HEI at the national level through the council of rectors.

- lack of repositories an meta-platforms: the national repository SABER has not been accessible since 2019, and this aspect corresponds to a loss of access to information collected since its creation in 2009, where 6 institutions were included. Currently, Mozambique has only 2 institutional repositories, being evident the need to establish policies aiming at involving a larger number of institutions in a new national repository including all the information contained in SABER, involving all higher education and research institutions on a common platform. At the individual level, there is a need for institutions to create and establish digital repositories to promote open access, preservation and memory and to contribute to the visibility of the educational and research institutions and the authors themselves. The creation of a common platform will then allow an integrated search of all scientific literature databases that Mozambique has access, being also crucial to include a culture of scientific research in the course of studies.

- lack of OA policies and mandates: the growth of institutional repositories is a relatively inexpensive mechanism for enlarging access to publicly funded research in Mozambique. For this, it is important for Mozambique to move forward with the implementation of national OA policies and mandates. As mentioned, it is necessary that institutions create their repositories or that they are hosted on a common platform (a national and institutionalized repository) ruled by institutional policies and mandates, which should have the support of the government and the council of rectors.

- lack of IP policies: OA promotes access to knowledge, but it is necessary to build policies involving all actors to break the barriers. There are still many fears within the scientific community about

the availability of scientific works in OA, namely those related to breaking copyrights entered into in contracts with publishers. The conditions existing in most universities, concerning copyright policy, dispense with these rights, are exclusively dependent on members of their academic body. In this way, researchers and professors can cede these rights to whomever they wish, when they decide to publish the results of their work. To this end, there are licenses on the use of intellectual material, such as the Common License/Creative License, which follow the rules of copyright, allowing free access to documents deposited in institutional repositories. Another of the most mentioned concerns, when addressing the availability of publications in OA, is related to the risk of plagiarism, being considered that the deposit of scientific production in digital repositories increases this risk, facilitating the appropriation of ideas and results released. This concern is accentuated when sensitive or confidential information content is involved - for political reasons, of commercial value, or personal data. As a solution to these situations, it is possible to establish the embargo for a certain period or even to change the writing of the text available in OA. Many publishers allow authors to deposit their articles in repositories only after an embargo period, usually six months at least. These doubts seem to be the most evident and those that pose greater barriers on the part of authors regarding public availability.

- low-quality and low-sustainability of OA journals: concerning scientific journals, as mentioned in Chapter 5, the RC-UEM project faces numerous difficulties due to the research panorama and the quality of scientific production in the country. The OA movement in Mozambique has had difficulty moving forward not only because of the lack of OA policies and mandates, but also because many authors still prefer to publish in journals with greater impact, not caring if the article will have restricted access. Another difficulty in creating a prevalent journal model is that each disciplinary field has a specific demand involving the publication of knowledge. It has to be taken into account that the expenses for the creation and maintenance of a journal are not just the installation of a publishing system. The constant costs, especially those related to editorial production such as secretariat, text revision, layout, preparation of originals, and other technical care, are fixed expenses, that tend to increase, and are rarely considered in the decision-making process of creating a scientific journal. This gives rise to the difficulty of meeting standards of excellence and consolidating the specialized scientific publishing market. Thus, many publications are produced with less than desirable quality, irregular periodicity, and high levels of endogeny, and thus, in a short time, destined to be part of the already high mortality levels of scientific journals in Mozambique. Taking into account the mentioned aspects, it is necessary to:

- invest much more in scientific research to create stronger factual bases, produce new knowledge and technological innovation, promoting a greater number and quality of scientific article submissions;
- encourage professors, researchers and students to publish their work in existing OA scientific journals in the country, as a way to prevent magazines from "dying" prematurely due to lack of content. The advent of publications in digital format and OA makes this even simpler and seemingly less costly;
- encourage scientific associations and universities, especially graduate programs, to invest in the creation of OA scientific journals, indexed in qualified databases for scientific literature;
- create mechanisms that reduce the review process time so they don't put in causes the release of each issue of scientific journals. The academic and scientific community must invest in the quality of the articles to be submitted so that they can be accepted. Taking into account the absence of national and institutional OA policies, UEM should invest in the creation of its institutional OA policies and register, if it manages to establish high levels of quality, the RC-UEM in the African directory of scientific journals.

e-Learning issues

To alleviate existing gaps in access to education, of the approximately 50 higher education institutions in Mozambique, some have decided to use advanced e-learning as an alternative to face-to-face teaching.

As mentioned in Chapter 5, as example, the cooperation between the UCM and the UCP allowed the creation of a doctoral program in educational sciences in Mozambique. In this sense, the doctoral program arises from the need to train teachers in one of the UCM campuses located in the province of Nampula in the northern region of Mozambique. To complete the course, it was necessary to adopt a training model that would ensure that the curriculum developed in Portugal was also fully complied with this new context. Taking into account the need to follow the contents established in the curriculum and, as it was impossible to do so in person, an e-learning model was defined with a plan centered on the Mozambican reality [104].

The specific measures of this plan, reflect the existing constraints and the actions to overcome them. In particular:

- taking into account the lack of qualified human resources and teaching materials made available on the e-learning platform to support the learning process, the doctoral program was structured and developed by UCP;

- taking into account the doctoral program location and cost reduction, it was considered a training model based on distance learning. Due to the lack of resources, such as the difficulty in accessing Internet tools, and the reduced students' digital proficiency, the adoption of blended learning strategies was considered, i.e., the hybrid learning modality. The adopted model seeks to combine pedagogical practices in face-to-face and distance learning, with the aim of improving student performance in both types of teaching. In this sense, the course was built by combining online materials and in-person classes to optimize knowledge retention.

In general, several constraints and adjustments for e-learning need to be considered, which may become a challenge in developing countries, namely:

- it is necessary to carry out several adaptations, to diversify the teaching and learning modalities. The interaction between teacher and student in distance learning is subject to a set of constraints that are different from those that occur in person. It is also necessary to ensure that everyone has the same tools to support learning;

- Internet connectivity and access problems are identified as one of the most significant obstacles to an effective response to the establishment of e-learning. While a weak communications infrastructure jeopardizes distance learning, providing universal access to reliable and affordable connectivity is not simple, and the move to e-learning will increase inequality and disadvantage the poorest students;

- high-quality Internet services are needed in distance learning. Connections must not be interrupted frequently and increased bandwidth for sharing content, especially in synchronous collective sessions using web conferencing software such as Adobe Connect or Webex, is needed. The lack of quality of service on Internet access leads to the abandonment of the e-learning model. As mentioned in Chapter 5, in addition to the problem of connectivity, most students are used to the close presence of teachers and hardly do without personal contact, which is essential to promote socialization that facilitates the process of learning building;

- the financial resources for technology to reach most students are a problem. There is a restricted infrastructure, the integration of technological platforms for education in African countries, and in particular in Mozambique, faces enormous challenges due to cultural, political and economic factors. This stresses the need to consider e-learning strategies and, in particular, the use of audio and video-based applications to support the formation of a large number of students with economic

difficulties and little access to ICT. As a basic requirement for the development of any learning strategy outside the classroom, it is necessary to have electricity, at an affordable price. Too many zones of Mozambique, particularly rural areas, do not have access to electricity. Most of the poorest and most marginalized students are found in rural areas, a problem that exists in most countries in Africa. Enabling everyone to have affordable and sustainable electricity will be the key to developing balanced economies in Africa;

- personal devices and technology are required. Laptops are expensive compared to tablets and smartphones, and most people can buy a smartphone for personal use. The diversity of mobile digital devices on the market and the use that citizens already make of them highlight the spectrum of possibilities they offer, both on a personal and academic, social and occupational level, which can be considered a means of support for distance learning. Currently, access to knowledge and information is no longer restricted to specific physical spaces: schools, universities, libraries, etc. In this way, learning becomes increasingly mobile. In fact, the emergence of the paradigm of ubiquitous education derives from the benefit obtained from the potential and possibilities that the Internet offers, through mobile devices, at any time and in any part of the world;

- the lack of teacher training and professional development on the inclusion of technology in teaching means that teachers are poorly prepared to give an effective distance learning response. So, it is important to invest in the reinforcement of skills, professional development and teacher training in terms of e-learning. This involves actions of mutual cooperation at national and international levels, sharing resources, as well as experience between teachers. The problems identified reveal the need to create a video management service for the simple registration and distribution of teaching content (classes). As in the case of educast@fccn service, provided by the Portuguese NREN, this platform should allow: recording of classes, uploading to the central server, editing and subsequent publication, integration in e-learning systems, portals and websites. The central system guarantees the necessary post-processing, so that contents are available to students through the Internet and mobile devices, in the streaming delivery format. In this case, MoRENet should be the main responsible for promoting the production, distribution and consumption of educational, cultural or entertainment content in a national audiovisual format. This solution also allows students to view the videos of classes afterward at their own pace. Podcast as a service supported by MoRENet can be viewed as a comprehensive alternative/complement to e-learning in Mozambique, enrolling and supporting multiple higher education institutions in a large-scale vision and deployment of e-learning.

Despite the enormous potential of this e-learning strategy, there are critical success factors that help managers define the main guidelines for the implementation of a podcast platform in Mozambique that should be considered, namely:

- definition of policies, rules and procedures at the national level that should lead to the successful implementation of a podcast platform;
- selection of the appropriate supporting technologies, that is, use the technology in favor of education, taking into account the network capacity, the existing resources and the location of the service;
- implementation of a solution based on the Mozambican reality, i.e., including technical assistance, considering the dissemination of the podcast service and the training of teachers and students are important factors for success;
- collaboration and international cooperation can be considered as a mechanism for joint development between countries in response to common challenges in terms of technical and technological management. It is important to seek experiences with existing success stories, enabling the transfer of knowledge and techniques from other countries and from international organizations;
- identification and acquisition of materials and registration equipment for deployment, which also involves the constitution of a technical team that responds to the needs of the participating institutions.

MoRENet issues

The challenges for the effective implementation of MoRENet are enormous considering economic, social, technical, technological, infrastructural and sustainability aspects. At this moment, MoRENet can be considered operational, existing more and more HEIs using the national platform and sharing ICT. The number of institutions linked to MoRENet rose from eighteen, in 2015, to one hundred and forty-three in 2018, across the country. Currently, 160 HEIs, scientific research and Professional Technical Education institutions are interconnected to MoRENet. The Mozambican government is making efforts to mobilize funds to ensure that MoRENet is efficient and sustainable.

The establishment of MoRENet has been facilitating interaction in academia, mainly between students, professors and researchers, also promoting an interaction for the exchange of ideas and access to national and international knowledge resources at shared and accessible costs. Nevertheless, the installation of

the wireless network on university campuses is another challenge, aimed at increasing, diversifying and facilitating the connection to the Internet for the entire student community, teachers and researchers.

Following the previous discussion, it was possible to see that there are several factors conditioning the successful implementation of services dedicated to the academic and scientific community, with emphasis on technological infrastructure and the regulation of e-learning. In this context, it is crucial that MoRENet assume a leadership role in the support of advanced services to the enrolled community, being here proposed that MoRENet provide e-learning services combined with national higher education and research programs, as well as international cooperation. These aspects will allow to broaden the impact of e-learning initiatives and promote the development of Mozambique, both scientifically and socially.

7.3 Summary

This chapter has discussed the challenges and next steps for the sustainable deployment of the proposed open science model, taking the African context, and then refining it to the Mozambique ecosystem.

The debate has focused on issues related to OA, e-learning, and NRENs, as these are the main target vectors in the proposed model. The critical factors that may impact the effective deployment of OA and distance learning were clarified, and strategies to overcome the identified challenges were presented. The role and sustainability of NRENs supporting large-scale connectivity and advanced services for the enrolled community were also stressed.

The provided encompassing discussion centered on Africa, has also the benefit of providing a global perspective that other developing countries, apart from Mozambique, can benefit from.

Chapter 8

Conclusions and Future Work

This chapter presents a concluding review of the research work carried out. Initially, an assessment of to what extent the objectives outlined have been fulfilled is provided, then the main contributions of the thesis are discussed, and, finally, possible future research directions are pointed out.

8.1 Summary

This research work was devoted to discussing the problem of science growth in developing countries, focusing on the role of NRENs, OA repositories, research management IS, and distance learning strategies in higher education for expanding knowledge frontiers.

By studying: (i) NRENs and OA initiatives worldwide, CRIS directives, and distance education best practices; (ii) Portugal and Africa as case studies; and (iii) the Mozambique scientific ecosystem, it was possible to identify the main difficulties for the deployment and sustainability of open science in the African context, more specifically in Mozambique. From this study, it also becomes evident, that despite the strategic plans for scientific growth in Mozambique, the country still faces many difficulties in reaching a consistent scientific development level.

It is within this context that the motivation of this work was raised, being its main objective defined as *to devise an evolutive and sustainable model for science growth in Mozambique, which considers the scientific and higher education ecosystem of the country, and it is focused on open science, science management, distance learning, and technological infrastructures supporting science and education*.

From the definition of this research direction, several research questions emerged, related to the understanding of the main vectors and obstacles to the scientific development of Mozambique, and the identification and adjustment of best practices worldwide to accelerate the scientific development of the country.

Fulfilling the main objective and answering the related research questions has led to the proposal of an

open science model that considers not only the importance of NRENs and OA but also stresses the new directives and trends of information systems for managing science, making specific recommendations aiming at fostering the growth, sharing and disseminating of the research conducted in Mozambique. Through the present study, is also expected to increase the perception of science vectors to other developing countries to promote their development both scientifically and socially.

8.2 Reviewing results and contributions

NRENs play a key role in supporting research and teaching activities both at national and international levels, being an important vehicle for knowledge dissemination and growth. From the study carried out, having African NRENs as the main focus, it was visible that the technological infrastructures and regulation are crucial factors of success in the implementation of services dedicated to the academic and scientific community.

Regarding Mozambique, it was evident that, after an initial period with significant difficulties and failures, the expansion of Mozambique NREN occurred and integrates nearly 160 institutions around the country. The implementation of the national backbone was one of the biggest challenges and connectivity is the only service provided at this stage. Scientific research in Mozambique is also emerging, having the science, technology and innovation strategy of the country, launched in 2006, and the creation of NRF, stimulating the growth of research activities.

Accessing, sharing, and disseminating scientific production are essential factors that contribute to the development of societies in various fields. Given this perspective, this work addressed the challenges associated with information access on two main fronts: the access to scientific literature through OA, introducing a worldwide perspective and the distinct experiences of Portugal and Africa; the key role of NRENs in supporting and providing information access services dedicated to the academic and scientific community.

Taking the relevance of OA repositories for expanding knowledge frontiers, this work has focused firstly on the challenges and strategies for developing open repositories in the African context. By studying OA initiatives and policies worldwide, and taking the Portuguese experience as a case study, it was possible to identify the main difficulties and directions for the deployment and sustainability of OA repositories in Mozambique [5, 3, 9, 10].

Portugal, with the B-on service, acquires scientific content based on a cycle that ensures the provision of comprehensive scientific literature, involving two access regimes "all-for-all" and "some-for-some",

and a well-structured negotiation and acquisition process with publishers. Although the contents management software used brings high costs, the demand for international scientific titles has grown since its creation, and the strategy for preserving contents is advantageous, guaranteeing that contents acquired in established contracts are not lost.

Regarding OA, Europe is a leader in the number of repositories, OA policies and mandates. National and institutional EU directives have benefited the academic and scientific community by considering self-archiving of all scientific output resulting from public funding, including the research data. In terms of institutional initiatives, the promotion of self-archiving of documents produced in institutions has been promoted, including MSc and PhD dissertations. RCAAP, in Portugal, has proved to be a success for institutions that did not possess repositories, which now can have their repositories centrally hosted in RCAAP. Thanks to existing mandates the number of documents from the national repository is high.

In Africa, there is still much to do and the challenges for promoting the growth and access to scientific literature are enormous. The access to international scientific content in Africa is still sustained by international organizations and projects that negotiate with the member countries or institutions the access without charge. In the case of Mozambique, UEM coordinates this collaborative project. The OA movement is recent in Mozambique and most of the initiatives are also being conducted by UEM. The deployment of MoRENet could result in an increased collaboration on OA initiatives developed by UEM, allowing the expansion of a national repository and of the scientific journal RC-UEM.

Considering the barriers presented in the context of OA in Mozambique, it is important to gain political support for the OA initiative launched in 2009, with the creation of the formerly SABER repository, and to define policies and mandates. Another aspect that deserves special attention is intellectual property protection. The strategy launched by the MCTES exists but remains to be implemented, being one of the barriers to the growth of the RC-UEM journal and SABER repository.

These results stress the relevance of cooperation to foster knowledge in developing countries, by learning from success cases and sharing experiences, and to obtain technical and funding support in an initial deployment phase. The development of NRENs is a key aspect to provide a consistent technological and communication platform engaging the research and education community in the common objective of promoting knowledge growth [6]. This has led to the proposal of directions for the join evolving and creation of a national repository and MoRENet which will enable the growth of the number of documents deposited and the number of existing repositories [7, 8]. Providing broad dissemination and access to science, combined with the national research programs and international cooperation, are important steps for Mozambique's development both scientifically and socially [5, 3].

Regarding the implementation of e-learning strategies and services in Mozambique, as generically in Africa, the opportunities and challenges are manyfold. Only those who have access to the Internet can access this type of learning model. For the most part, neither students nor teachers have any learning and teaching experience outside the classroom. Thus, lack of access to technology, inadequate learning environment at home, and lack of access to teaching materials represent real issues. For teachers, the main obstacle was the lack of adequate training to create and manage distance learning programs. This was compounded by the lack of infrastructure (connectivity, electricity, computing devices), and the lack of adequate learning materials. The conclusions are evident: the poorer the students and the more dispersed they are geographically, the greater the risk of falling behind in education. The government must invest in education systems more suited to this century. e-Learning, by definition, is a convenient response, requiring not only electricity but also access to a data connection and devices through which e-learning materials can be accessed. These are in short supply in many parts of Africa, including Mozambique, emphasizing the digital divide in education between those who have access to technologies and those who do not. National curricula must also be adapted to enable more effective distance learning.

This work has stressed e-learning relevance for increasing knowledge sharing in the academic and scientific community, and the need for training human qualified resources. In this context, important national and international initiatives in the field of e-learning were presented, taking into account the Portuguese NREN e-learning service as an example of a successful case for promoting collaboration, production, and sharing of knowledge using e-learning platforms. Also, to improve deployment and sustainability, has been proposed that African NRENs put e-learning services on the frontline combined with the national research programs and international cooperation, as these are important steps for enlarging the impact of e-learning initiatives and fostering the scientific development of African countries [11, 12, 13].

Facing the above discussion, access to ICT in developing countries is considered crucial to promote development and integration into a knowledge society. Following a worldwide trend, NRENs infrastructures and advanced services supporting, for instance, OA and e-learning, are considered key aspects to improve global access to knowledge, fight illiteracy and increase access to higher education. Comprehensive NRENs projects, such as AfricaConnect3, are also crucial to spreading digital infrastructures and technologies, enabling broadband connectivity and services for researchers, students and institutions. As a final remark, the proposed evolutive open science model [6, 7, 8, 13], thoroughly debating and interrelating the above-mentioned vectors, is a step forward regarding OA representativeness in Mozambique, contributing to increasing the visibility, access, and dissemination of scientific production at a national level.

8.3 Prospect for future work

Facing the objectives of this research work, firstly introduced in Chapter 1 and summarized in Section 8.1, the problem of science growth in developing countries and, in particular, Mozambique, was studied taking distinct, while interrelated, perspectives. From the analysis carried out along this work, several topics have been identified as deserving further research. These topics derive from the large scope of the research sustaining the definition of the proposed model for science growth in Mozambique. This model has as main target the contexts of open science, science management, distance learning, and technological infrastructures supporting science and education. As works to be developed from this, the following is suggested:

- Facing the distinct ICT levels of developing countries, the study of the maturity and business model of NRENs are aspects requiring a closer analysis. Usually, this type of assessment does not need to be carried out with the aid of a specific tool, in fact, this action can be done through a set of specific questionnaires. This assessment comprises 6 levels of evolution namely [113]:
  - Level 0 refers to the absence of an NREN and the unawareness of the need for one. The unawareness can sometimes result from a lack of exposure to functioning NRENs and the benefits that flow from them. The scarcity of bandwidth features can make room for the type of lobby that can lead to the next step;
  - Level 1, despite the absence of an NREN, is characterized by an awareness of the benefits and the need to implement it. This awareness often derives mostly from exposure to functioning NRENs or from failed attempts at academic collaboration;
  - Level 2, despite the absence of an NREN, the need for its creation is already being discussed. A structured discussion does not, by itself, lead to the formation of an NREN, the conversation can take years, with no results. Such discussion can be carried out under the auspices of existing structures, such as university vice-rector associations, through donor initiatives, or it can be anticipated by changes in the technical or regulatory environment. Leadership is the critical factor in this and the next two stages, as conversation alone does not lead to the creation of an NREN;
  - Level 3 requires the establishment of a commitment, that is, when potential beneficiaries sign a formal commitment among themselves, by signing a memorandum of understanding to establish an NREN and use its services;

- Level 4 marks the first point where one can speak of the existence of an NREN, the establishment of an organization with a legal entity, thanks to a coherent offer of services. The memorandum of understanding was translated into a formalized organizational structure and contracts with service providers and beneficiary institutions. The new NREN may simply be a consortium to encourage collective purchasing power. These consortia have the potential to implement more mature NREN structures;
- Level 5 corresponds to regional connectivity, which is achieved when the NREN is technically and coherently participating in regional, continental, or global connections with other NRENs or groupings of NRENs;
- Level 6 is associated with a fully mature NREN with an offer of services elaborated on the type of networks that characterize Europe, North America, and comparable contexts. It represents an NREN that is widely connected at high speed to many other networks and resources. The NREN provides a variety of value-added services such as cloud and grid computing resources, user-controlled lightpaths, video conferencing, and federated identity services.

In this context, a capability maturity model gives rise to a roadmap design and helps to identify intervention or leverage points. In particular, models of this type allow us to clarify obstacles and think about how they can be removed or bypassed. For example, in some of the early stages of the formation of the NREN, they cannot take place if the policy or regulatory environment is unduly hostile. In these cases, politics and regulation are the very spaces in which intervention is needed. In this sense, the role of leadership is critical at all levels, but especially in the initial phases, and it is this same leadership that makes it possible to move from the conversation to the commitment to the creation of an NREN and that translates the vision into action.

Often, the main objective of creating an NREN is to provide accessible Internet to the academic and higher education community. Later, advanced services are also provided. With regard to the business model, according to the study carried out in [114], the structuring of NREN consists of the governance model, the organization of NREN, and the tariff model. These issues need to be determined together with potential NREN members in a transparent and interactive way. All of this is included in NRENs financial model providing, hopefully, a long-term sustainable financial plan. In the case of Mozambique, the NREN business model has guaranteed funding of more than US$5 million from donors to implement the NREN. The donors' decision was based on the business model which demonstrated that once the NREN was established and the first three years were supported

by external funding, the NREN would be financially sustainable and able to operate without external funding.

In distinct African countries, the business model involved convincing the national telecommunications operator to support NREN by providing a nationwide Gigabit network backbone free of charge. In this sense, the telecom operator sits on the NREN governance board and supports NREN wherever it can, bearing in mind that by creating more awareness and skills in ICT in the country, revenues will increase. In addition to the telecommunications operator, other government organizations provide support to the NREN, for example, the national telecommunications regulator that provides a budget to overcome the challenges of the last mile outside the capital [114].

These distinct perspectives stress and unveil the need for further study in adapting NRENs business models to distinct ICT contexts.

- OA is today one of the pillars of the open science movement and a practice that has been gaining relevance for nearly two decades in the scientific community, involving science and technology policies in different regions of the world. Despite notable advances in the implementation of OA, many challenges remain, in particular related to a publication market still dominated by large publishers, who charge subscriptions, and with some widely recognized dysfunctions, especially by the academic community and scientific research funding entities. While common directives have been envisioned to promote OA in developing countries, being detailed for the Mozambique ecosystem, these aspects need to be further studied and articulated with the scientific reality of each country.

- Institutional repositories are an important part of the science management ecosystem. To integrate these systems into a broader ecosystem, it is necessary to ensure compliance with a regulatory framework that guarantees interoperability between the systems. Interoperability between information systems that support scientific and academic activities must be analyzed in greater depth, remaining for future work. Existing directives in developing countries regarding umbrella research systems and IDs have been discussed, needing a closer look facing developing countries' science awareness and reality.

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