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Sustainability of digital libraries: a conceptual model and a research framework

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Abstract This paper aims to develop a conceptual model and a research framework for study of the economic, social and environmental sustainability of digital libraries. The major factors that are related to the economic, social and environmental sustainability of digital libraries have been identified. Relevant research in digital information systems and services in general, and digital libraries in particular, have been discussed to illustrate different issues and challenges associated with each of the three forms of sustainability. Based on the discussions of relevant research that have implications on sustainability of information systems and services, the paper proposes a conceptual model and a theoretical research framework for study of the sustainability of digital libraries. It shows that the sustainable business models to support digital libraries should also support equitable access supported by specific design and usability guidelines that facilitate easier, better and cheaper access; support the personal, institutional and social culture of users; and at the same time conform with the policy and regulatory frameworks of the respective regions, countries and institutions. It is also shown that measures taken to improve the economic and social sustainability should also support the environmental sustainability guidelines, i.e. reduce the overall environmental impact of digital libraries. It is argued that the various factors affecting the different sustainability issues of digital libraries need to be studied together to build digital libraries that are economically, socially and environmentally sustainable.

Keywords Digital libraries · Sustainability · Social sustainability · Economic sustainability · Environmental sustainability

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1 Introduction

The word sustainability has gained much importance over the past few years, and it is now discussed in almost every business and in every sphere of life. According to the US Environmental Protection Agency (EPA), sustainability "creates and maintains the conditions under which humans and nature can exist in productive harmony that permit fulfilling the social, economic and other requirements of present and future generations" [1]. There are three forms of sustainability viz. economic sustainability, social sustainability and environmental sustainability. Although the overall aim of any business or development is to achieve sustainability in all its three forms, in reality it is a major challenge because often measures are taken for achieving one form of sustainability influence or affect the other forms of sustainability. This paper discusses all the three forms of sustainability in the context of digital libraries. It identifies some factors that have impact on each form of sustainability. Relevant current research reports and papers are used, not to exhaustively review the developments in the specific fields per se but to illustrate various issues and challenges for the economic and social sustainability of digital libraries. Similarly the paper draws upon some current research in green IT and cloud computing to illustrate some issues of environmental sustainability that are relevant for digital libraries. Based on these discussions this paper proposes a conceptual model for sustainable digital libraries, and thus proposes a theoretical framework for study and research in this area.

2 Sustainability of digital libraries

Sustainable information refers to resources that facilitate integration of all the three parts of sustainable development

viz. social, economic and environmental sustainability, and contributes to the strengthening of the processes in which society is transformed according to the ideals of sustainable development [2]. Overall, the concept of sustainability has not been researched well either within the mainstream information science in general or within the context of digital libraries in particular [2,3].

A digital library is an evolving organization and comprises three distinct systems—viz. a *Digital Library* that provides digital content to its users through a series of functionalities that are controlled by some quality and policy measures; a *Digital Library System* which is a software system that supports the functionalities of a *Digital Library*; and a *Digital Library Management System* which is a generic software system that provides the appropriate infrastructure for the functionalities of the *Digital Library System* [4]. The Digital Library Reference Model (DRLM) [4] identified three categories of actors that are fundamental to the operation of the *Digital Library* service, viz.

1. the DL end-users: content creators and content consumers;
2. the DL managers: DL designers and DL system administrators; and
3. the DL software developers.

To study all the three forms of sustainability of digital libraries, it is necessary to identify the challenges that are associated with all the three systems that form a digital library, as discussed above, and also the activities and functions of all the actors. Furthermore, depending on the level of details that one wants to achieve, a study of the sustainability of digital libraries may also consider factors influencing the lifecycle of information—content and data from their creation to management, use/re-use, and disposal (when required, for example disposal of analogue information resources and also disposal of computing infrastructure and equipment used for creation, management, access and use of digital information) [5]. Although the DRLM [4] provides different levels of abstraction that lead from the "modeling to the implementation" of digital libraries, it does not specifically show how the different actors, and the functions and activities can support or influence the three different forms of sustainability of digital libraries. This paper aims to address this issue by proposing a conceptual model and a research framework for study of the sustainability of digital libraries.

Before developing a model and a framework for study of the sustainability, it is necessary to determine the target and various indicators, for each form of sustainability of digital libraries. In the context of digital libraries,

- the target for economic sustainability is to provide cheaper, easier and better access to quality digital information through a sustainable business model. The success can be achieved by building a sustainable business model—'for profit' or 'not-for-profit' depending on the service provider and their characteristics—as well as through measures for reduction of cost in the process of creation, distribution and access to information; and also by taking measures for reduction in the user time and efforts for discovery, access and use of information relevant to their specific needs, context, culture and work practices, etc.;
- the target for social sustainability is to ensure equitable access to information to build a better (well informed) and healthy society. The success can be achieved (a) by improved accessibility and usability relevant to the user context, culture, etc., and (2) by building tools and techniques for measuring and improving the impact of digital libraries in every sphere of life and society; and
- the target for environmental sustainability is to ensure reductions in the environmental impact of digital information systems and services. The success can be achieved by building appropriate tools and techniques as well as measures to reduce the greenhouse gas (GHG) emissions throughout the lifecycle of digital libraries.

Many of these factors are interrelated, and therefore cannot be considered in isolation. For example, the rapidly changing ICT infrastructure and information design to deal with digital content and data will have implications for all the three forms of sustainability of digital libraries: (1) on the economic sustainability because of the increasing costs, increasing levels of efforts or specific needs for the deployment of high-end ICT equipment for management of, and access to, information, etc. (2) on the social sustainability because of changes in the level of equitable access, and effects on the users' work and culture, and perhaps causing more social exclusion caused by the unequal, or even lack of, ICT and internet access, and (3) on the environmental sustainability in terms of increase in the GHG emissions due to quick changes in, and disposal of, the ICT equipment and infrastructure, and so on. Furthermore there are a number of external factors that form the foundations of digital libraries, such as the emerging ICT infrastructure and policies; the fast changing web, social networking and mobile technologies; the emerging intellectual property rights (IPR), privacy and security issues, and so on. Often these factors play a significant part in each area of sustainability and thus affecting the overall sustainability of digital libraries.

Some past research have indirectly touched upon the different forms of sustainability of digital information services. For example, a number of alternative business models for digital information services have been studied in the context of e-books and e-journal subscription models in libraries, and also in the context of open access models (see for example [6]). Similarly there have been many evaluation studies

focusing on the impact of digital library services. A significant amount of research has taken place in the broad area of user studies as well as digital literacy, social inclusion, etc. in the context of digital libraries (for a review see [7]). Recently, Chowdhury [3,8–10] has discussed the environmental issues and challenges of digital information systems and services. However, to date very little research has been undertaken addressing all the three forms of sustainability in tandem to understand the different factors that influence the sustainability of digital libraries, and their implications as well as their interrelationships in the context of the design, development and management of digital libraries [3].

3 Economic sustainability of digital libraries

As stated earlier in the paper, the target for the economic sustainability of digital libraries is to ensure cheaper, easier and better access to digital information through a sustainable business/funding model. Thus for digital libraries, economic sustainability can be achieved by:

1. building a sustainable business model supporting the economic, technological and manpower resources for the design, delivery and management of digital content and data to meet the present and future needs of the user communities and society, and
2. a sustainable model for providing the economic, technological as well as intellectual support for preservation of digital content and data.

Although it has been talked about in several publications, the economic sustainability of digital libraries still remains a challenge requiring further research and innovation [11].

3.1 Sustainable business models for digital libraries

While some digital libraries are based on commercial models, i.e. they require payment or subscriptions for access, many digital libraries have appeared over the past two decades or so that are free at the point of use. Such digital libraries are funded by:

1. governments, e.g. the US National Science Foundation providing support for the National Science Digital Library, or the National Library of Medicine as part of the US National Institute of Health providing funds for PubMed;
2. specific countries/institutions or consortia for example, various EU countries providing support for Europeana, or specific institutional repositories; and
3. charities, e.g. the Wellcome Library funded by the Wellcome Trust.

However, sustainable funding is still a major issue for many digital libraries. For example, it was reported that "the committed and received funding from 21 countries has meant that Europeana has fully covered both project-matching and operating costs through to the end of 2012. However for the year 2013, Europeana needs to raise additional funds of € 426,000" [12].

Very few of the earlier digital library evaluation studies focused primarily on the economic sustainability of digital libraries [13]. It is generally agreed that measuring the impact of information services in general, and digital libraries in particular, is difficult because it is not easy to convert the benefits of information services to Dollar figures. However, of late some studies have attempted to measure the impact of digital libraries on the economy as a whole. For example, the *Europeana case for funding* document [14] points out that over the past 5 years, initial EU investment of 150 million euros has resulted in 70 million euros of co-funding from Ministries in 21 countries. The document reports that these investments have facilitated massive digitization in different EU member countries and as a result over 30 million digital objects are now available through Europeana. It is also reported that as of 2013 "770 businesses, entrepreneurs, educational and cultural organisations are exploring ways of including Europeana information in their offerings (websites, apps, games etc.) through our API" [14]. The document also points out that Europeana has helped in the creation of new jobs; for example, it reports that in Hungary, "over 1,000 graduates are now involved in digitizing heritage that will feed in to Europeana. Historypin in the UK predicts it will double in size with the availability of more open digital cultural heritage". Such measures of the impact of digital libraries on the wider economy, job markets, etc. are essential, albeit often very difficult and time consuming, for justifying the case for funding, and thereby achieving the economic sustainability of digital libraries.

3.2 Open access and economic sustainability of digital libraries

The Green route to OA, that is based on self-archiving of research papers, has given rise to thousands of institutional repositories. For example, the OpenDOAR directory has over 2,500 listings of institutional repositories. However, different institutions follow different practices for the creation and management of institutional repositories. A recent survey of the funding and deployment of institutional repositories [15] notes that:

- institutions that mediate submissions incur less expense than institutions that allow self-archiving,
- institutions that offer additional services incur greater annual operating costs than those who do not, and

- institutions that use open source applications have lower implementation costs but have comparable annual operating costs with institutions that use proprietary software.

Most research funding bodies such as the European Union, Wellcome Trust, Research Councils UK (RCUK), US National funding bodies such as the National Institute of Health (NIH) have proposed their OA policies which will result in the development of various open-access institutional repositories and digital libraries. However, it will be interesting to see how economically sustainable will these repositories be under these newly introduced OA policies.

An earlier study commissioned by Jisc in the UK notes that there are potential economic savings for universities from OA. It notes that if the universities in UK continue to pay for journal subscriptions, as they do now, and also make their research output available through OA repositories, the amount of savings for universities, accrued from increased efficiencies in the research and library handling processes, could range from £0.1 million to £1.32 million per annum [16]. However, it should be noted that there are costs associated with running the institutional repositories. The Jisc study further noted that [16]:

- Annual operating costs for the institutional repository, including the cost of depositing items, range from around £26,000 to almost £210,000; and
- The cost of depositing a single article varies from around £6.5 to £15.4, with the annual cost of depositing into the repository all articles produced by each university ranging from just over £4,000 to over £75,000.

It may be noted that the costs of institutional repositories vary quite significantly depending on the size and nature of the universities, their research income and activities, number of research papers produced per year, and so on. Even if one takes an average of these two extremes, i.e. an average of £135,000 per annum for running an institutional repository, the total costs for 166 Higher education institutions would be £22.4 million per year which is nearly 15 % of the annual journal subscription budget of UK universities which is estimated to be £150 million [17]. The overall costs for managing institutional repositories would be much higher over the years especially when the digital preservation costs are included in this.

3.2.1 Economic sustainability of digital preservation

Economic sustainability has also remained a major challenge within digital preservation research. Over the past decade digital preservation research has mainly focused on the design, architecture and software solutions for management of digital collections and creation of various preservation tools [18]. Several attempts have been made to create a research agenda for digital preservation over the past few years. For example,

- in 2007, the Digital Preservation Europe (DP) project identified 10 fields of research in digital preservation, viz. restoration, conservation, management, risk, significant properties of digital objects, interoperability, automation, context, storage and experimentation; and
- a research seminar organized within the Dagstuhl series in 2012 addressed two major research questions viz. what role should the cloud play in preservation, and what steps should we be taking now to preserve the future of today's digital artefacts?

The EU DPimpact study demonstrated that "investing efforts and resources in securing future access to digital content makes a lot of sense in economic terms, as impacts—direct and indirect—will be clearly positive and growing as the DP (digital preservation) market start to "Cross the Chasm" by penetrating and developing the mainstream markets of the Information Society" [19, p 103–104]. However, the study also noted that the memory institutions had 'very limited' funding for preservation, as compared to 'limited' funding in the scientific and research institutions; and for business, companies and enterprises, the funding for preservation is done by project and is charged to overheads ([19, Table 2A, p. 34]. According to the Blue Ribbon Task Force report [20], economically sustainable digital preservation requires:

- a recognition of the benefits of preservation on the part of key decision-makers;
- incentives for decision-makers to act in the public interest;
- a process for selecting digital materials for long-term retention;
- mechanisms to secure an ongoing, efficient allocation of resources to digital
- preservation activities; and
- appropriate organization and governance of digital preservation activities.

The Blue Ribbon Task Force (BRTF) final report recommends that "sustainable digital preservation requires a compelling value proposition, incentives to act, and well-defined roles and responsibilities. Digital preservation is a challenge for all of society because we all benefit from reliable, authentic information now and into the future" [20, p. 5]. It concludes that sustainable preservation is a societal concern and transcends the boundaries of any content domain, and therefore all parts of society—national and international agencies, funders and sponsors of data creation, stakeholder organizations, and individuals—have roles in achieving sustainability. The economic sustainability reference model for digital

assets [21] divides the economic sustainability challenges into four major components, viz.

1. the economic lifecycle, i.e. the background against which a digital curation activity operates;
2. the sustainability strategy which should ensure that the curation activities meet BRTF's five necessary conditions for economic sustainability, viz. value, selection, incentives, resources, and organization/governance;
3. economic risks and remedies, i.e. the potential obstacles to achieving economic sustainability the potential solutions for mitigating or overcoming those; and
4. key entities, i.e. the digital assets, the curation process, and stakeholders.

Recognizing the lack of a continuous source of funding for digital preservation, an EU FP7 research project, called SHAMAN, proposed an enterprise architecture-based approach that enables the accommodation of digital preservation concerns in the overall architecture of an organization with the justification that although the preservation of contents is not a main business requirement, it is required to enable actual delivery of value in the primary business [22]. Although this may resolve some problems of preservation of digital records within an institution, this does not specifically resolve the issues that digital libraries and information services, for example institutional repositories, face for preservation of digital data and content to ensure future access.

Increasingly library and information services are moving towards a shared or consortia-based approach for digital preservation. The *HathiTrust* digital library brings together huge collections of partner institutions in digital form, preserving them securely for current and future access. In a recent move, seven European countries are launching the 4*C* (the Collaboration to Clarify the Costs of Curation) to help public and private European organizations invest more effectively in digital curation and preservation, sustaining the long-term value of all types of digital information [23]. The 4C partners involved are Danish National Archives (Denmark), DANS—Data Archiving and Network Service (Netherlands), Deutsche Nationalbibliothek (Germany), Digital Curation Centre (UK), Digital Preservation Coalition (UK), Humanities Advanced Technology and Information Institute (UK), Institute for Information Systems and Computing Research (Portugal), Jisc (UK), Keep Solutions (Portugal), National Library of Estonia (Estonia), Royal Library of Denmark (Denmark), Secure Business (Austria), UK Data Archive (UK). It is widely recognized that the costs of curation are currently hard to predict and secondly the short-term benefits are hard to define because curation implicitly addresses long-term challenges. It is reported that 4*C* will address both concerns and provide practical guidance that will help practitioners persuade executives to invest in new services [23].

3.3 Challenges

The major challenge for the economic sustainability of digital libraries arises from the very nature and purpose of digital libraries. Measuring the economic sustainability of a service sector, i.e. the tangible returns or measuring the value for money of a digital library service, is a major challenge, because often digital libraries do not make direct profits or tangible assets. Digital libraries produce "intangible" goods, such as development and progress in government, health, education, etc., and the overall society and the knowledge economy. The WorldBank Group report [24] proposes that one of the indirect measures for the economic sustainability of service sectors can be the growth in the human capital that is capable of engaging in sustainable development using fewer natural resources, alternative and innovative technologies and resources, and so on. Therefore, one should use such indirect measures or indicators for the economic sustainability of digital libraries. However, measuring the volume and value of such intangible goods is not only a challenging task, but may also take a long time to measure the impacts, e.g. the impact of a good digital library service on education and research, health, and so on. Although some indirect measures have been proposed, for example, as in the Europeana case for funding document, discussed earlier, certainly more research is needed to identify and develop different measurable indicators for the economic sustainability of digital libraries.

4 Social sustainability of digital libraries

Social sustainability may be defined as the maintenance and improvement of well-being of the current and future generations of people [25]. However, the concept of well-being can be defined differently in different contexts ranging from the equity of access to essential services for healthy lifestyle and well-being, to democratic and informed citizenship, to promotion and sharing of positive relations and culture, and so on. Many indicators of sustainable development have been proposed (see for example, [26,27]), but broadly speaking the main goal of the social sustainability of digital libraries is to ensure equitable access and ease of the use of digital information in every sphere of life and society.

Ideally speaking a socially sustainable digital library or information service should be ubiquitous, i.e. it should be embedded in the work and culture of people in such a way that they get access to the information that is relevant to their work or activities even without having to actively ask for it. Access is a rather broad term here that includes all the activities related to the discovery, access and use/re-use of

information for day-to-day business, pleasure, well-being, knowledge and understanding, and so on.

A number of parameters are associated with the social sustainability of digital libraries that have direct or indirect influence on equitable access, such as:

1. HIB (human information behaviour) and IS&R (information seeking and retrieval) issues;
2. Information and digital literacy issues;
3. Accessibility and usability issues including access to the ICT and internet facilities, digital library software and interface issues; and
4. Policy and legal issues.

4.1 Social sustainability and digital library

A number of models for digital libraries such as the 5S model (Streams, Structures, Spaces, Scenarios and Societies [28]) and the DRLM [4], and a number of software platforms such as DSpace, EPrints, Fedora Commons, Greenstone, etc., have appeared over the past two decades. Similarly a variety of tools, metadata standards and protocols for metadata harvesting, such as the OAI-PMH [29], have also been developed over the past few years. These digital library architectures, software, tools and standards aim to facilitate better and easier access to information, and thus improve the social sustainability of digital libraries.

The DRLM is built on six main domains, viz. content, user, functionality, quality, policy and architecture [30]. According to this model, the three systems, viz. the *Digital Library, Digital Library System*, and *Digital Library Management System* interact with the six domains to provide digital library services. The 5S model describes how various components of digital libraries interact or relate to each other. For example, digital objects are composed of *Streams* (bit streams) and *Structures* (e.g. structural metadata specification), that can be accessed through *Spaces* (e.g. indexing) through some *Scenarios* (e.g. sequences of events or actions such as searching, browsing, etc.) created by, or designed for, some *Societies* (e.g. user communities). Thus both the models recognize that digital libraries deal with digital objects that need to be managed and processed for providing access to the user community through a series of functions. DRLM also emphasizes on the quality of the content and services, and the policy issues. Therefore, these models implicitly argue in favour of the social sustainability of digital libraries which depends on a series of functions and policies for better organization, indexing, linking and retrieval of digital information that are appropriate for the context, culture and practices of the user community and society. Usability of digital libraries is often affected by the user needs and expectations that are set, often very rapidly, by the recent developments in the internet and web technologies, especially the popular search engines and digital information services. However, as discussed later in the paper (in Sect. 7), these models do not make provisions for explicitly addressing the challenges associated with all the three forms of sustainability. This is discussed in more details in Sect. 7.

4.2 HIB and IS&R issues

HIB and IS&R have remained the two most widely researched areas of information science for the past few decades giving rise to several models in information science in general (for details see [31–33]) and in the context of digital libraries in particular [34,35]. These models discuss various personal, contextual, social, cultural and technological issues that influence access to, and use of, digital libraries.

As discussed in the previous section, open access has become a major agenda amongst governments and research funding bodies. However, still there are some major cultural issues that need to be addressed to make it a success. For example, one may argue that the Finch Report [17] and RCUK OA policies based on the APCs (article processing charges; discussed in Sect. 4.5), may create a situation where publication of a research paper may be decided not only by its quality but also by the affordability of the authors and institutions to pay the APCs of a target journal. Furthermore, national research assessment exercises, like the UK research excellence framework (REF), Australian excellence of research in Australia (ERA), and more importantly academic and research appointments and promotions are still very much driven by the assessment of quality of research in journals and conferences with high impact factors. These assessment measures may affect the social sustainability of open systems.

4.3 Information and digital literacy issues

Like human information behaviour, information literacy has also remained a major area of research in information studies. There are other related areas of research like digital literacy, digital divide, social inclusion, etc. Access to, and effective use of, digital libraries can be significantly affected by poor information and digital literacy of people [7]. A November 2012 BBC news [36] reports that 16 million people in Britain, i.e. about one in four, or one in three in the adult British population, do not have the basic Internet skills. It may be safely assumed that this is not an isolated case and many countries in the world have comparable, or even worse, information and digital literacy skills causing social exclusion. In the context of digital libraries, social exclusion may be caused by a number of factors ranging from the lack of adequate access to ICT infrastructure and services, to the lack of digital and information skills that are the pre-requisites for successful access to, and use of, digital library services.

4.4 Accessibility and usability issues

Access to, and effective use of, digital libraries can be significantly affected by digital divide that is often manifested by [37]:

- the social divide which is characterized by the difference in access between diverse social groups;
- the global divide which is characterized by the difference in terms of access to the Internet technologies; and
- the democratic divide which is characterized by the different applications and uses of digital information to engage and participate in social life.

Different indicators may be used for assessing the different manifestations of digital divide [37]. Furthermore, digital divide is not only prevalent in the developing world, but also amongst various communities within the developed nations. For example, about a third of the US households do not have a broadband connection, and only about two-thirds of the 27 EU countries have a broadband connection at home [37]. So, the vision of the Europeana digital library to provide digital information and culture to everyone in Europe cannot be fully utilized because two-thirds of the EU homes do not yet have a broadband connection. The situation in the third world countries is even worse.

Usability of digital libraries is often affected by the user needs and expectations that are set, often wrongly, by the search engines. In a usability study of the Europeana digital library it was noted that young users' information needs and search strategies and expectations were quite different from those of more matured users [38]. The study further noted that many younger users wanted to be able to download, annotate and share digital objects. The latter is a relatively new phenomenon which is caused by the recent proliferation of the easy-to-use search engine services that have created a different set of expectations, especially amongst the younger users.

4.5 Policy and legal issues

Design and management of digital libraries are influenced by several policy issues. For example, the recent policies of various research funding bodies with regard to open access can have a significant impact on the economic and social sustainability of digital libraries. Research and funding bodies and institutions in many countries now support the motto of open access and encourage researchers to self-archive their published research papers, some even make it compulsory. For example, the public access policy of the US National Institute of Health (NIH) states that:

"all investigators funded by the NIH submit or have submitted for them to the National Library of Medicine's PubMed Central an electronic version of their final, peer-reviewed manuscripts upon acceptance for publication, to be made publicly available no later than 12 months after the official date of publication." [39]

The Wellcome Trust have also introduced a similar open-access policy that:

"requires electronic copies of any research papers that have been accepted for publication in a peer-reviewed journal, and are supported in whole or in part by Wellcome Trust funding, to be made available through PubMed Central (PMC) and Europe PubMed Central (Europe PMC) as soon as possible and in any event within six months of the journal publisher's official date of final publication" [40]

The newly introduced OA policy of the European Commission [41] stipulates that as of 2014, all research papers produced with funding from EU Horizon 2020 will have to be freely accessible to the public. The process of self-archiving has given rise to several specialized digital libraries like PubMed Central, and has given rise to institutional repositories at many specific institutional levels.

The Gold OA model has been adopted by many journals whereby they have introduced article processing charges (APCs), and there are now some hybrid journals that follow both the subscription and APC-based open-access model. Some funding bodies have introduced inclusion of APCs within their research funding models. For example, the OA policy of the Wellcome Trust states that the Trust, where appropriate, will provide their research grant holders with additional funding, through their institutions, to cover open-access charges. The European Commission recommends the following two options for OA [41]:

- Gold OA where research papers will be made immediately accessible online by the publisher and the researchers will be eligible for reimbursement of the APCs from the Commission; or
- Green OA where researchers will make their research papers available through an open-access repository no later than six months after publication (or 12 months for articles in the fields of social sciences and humanities).

A number of social, institutional and cultural issues are involved here. For example, it is not clear how the APC model of Gold OA will be implemented, and similarly how the self-archiving of research papers will be adopted by the academics and researchers across all the education and research institutions and disciplines.

Access to, and use of, digital information is often hindered by the inappropriate, and often stringent, intellectual property rights (IPR) and complex digital rights management (DRM) issues. This has been identified in several studies (see for example, [42–44]). Considering the various recom-

mendations of the Hargreaves Review [44], the UK Government commissioned a feasibility study that recommended the development of a *Copyright Hub* to serve a number of functions including [45]:

- Information and copyright education;
- Registries of rights;
- A marketplace for rights-licensing solutions; and
- Help with the orphan works problem.

The report concluded that a number of issues existed with copyright licensing making them unfit for the digital age [45]. However, it will be interesting to see how the new IP laws influence the publishing industry and digital libraries.

5 Environmental sustainability of digital libraries

Digital libraries are based on a variety of ICT infrastructures that run various information systems and services and the overall lifecycle of a digital library. ICT has a profound impact on the environment causing about 2 % of global greenhouse gas (GHG) emissions [9,10]. GHGs comprise carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF_6), but it is generally expressed through a common metric of CO_2-equivalent emission [46].

The information services sector, by virtue of making extensive use of ICT infrastructure and equipment, generates a significant amount of GHG emissions. In 2010 Google's overall consumption of electricity was reported to be 2.26 million MWh [47]. This is equivalent to the annual emissions from about 11 power stations in Britain [9]. Another estimate shows that about one billion Google search is conducted every day, and thus even on a conservative estimate, one billion grams or 1,000 tonnes of CO_2 (carbon dioxide, a measure used to show GHG emissions) is emitted only for Google search every day [48]. This does not include the client-side ICT and energy usage figures. It is estimated that the Internet consumes between 170 and 307 GW (GigaWatt) of electricity which is equivalent to 1.1–1.9 % of the total energy usage of humanity [49]. The HE institutions (HEIs) in the US produce 121 million tonnes of CO_2 in a year which is equivalent to nearly 2 % of total annual GHG emissions in the US, or about a quarter of the entire State of California's annual emissions [50]. It is estimated that in 2008–2009, HEIs in the UK alone used nearly 1,470,000 computers, 250,000 printers and 240,000 servers; and it is estimated that there would be 500,000 tonnes of CO_2 emissions from this electricity use [51].

Some data related to the environmental impact of information services based on print and digital content are provided by Chowdhury [10]. Studies also show that use of modern technologies like cloud computing can reduce both the economic and environmental impacts of digital information [3]. In the UK, Jisc is promoting the idea of using the cloud computing technology for providing data and information access services for the HEIs that can reduce the environmental costs of information services and the ICT infrastructure costs. Some US universities are also taking similar initiatives in developing cloud-based systems for managing research data and information [50]. In The Netherlands, SURFnet is also taking several measures to promote the use of cloud computing for higher education and research.

Thus, cloud-based information services can improve the environmental sustainability of digital libraries and information services [3,9]. However, a number of social-, cultural- and user-related issues are also associated with cloud-based information services, e.g., access and management issues related to sensitive data and content, information behaviour of users in relation to remote access to data and content; institutional and user culture and practices in relation to access and use of remote digital content and data, and so on. To date no research has addressed all of these issues in tandem in relation to digital libraries, and specific user communities and contexts.

6 A research framework for sustainable digital libraries

Figure 1 presents a generic model and a theoretical research framework for study of the sustainability of digital libraries. At the core, it shows that a digital library connects users with digital content and data using the appropriate ICT. It also shows that while a sustainable digital library needs sustainable funding models, appropriate measures should also be taken to achieve the social and environmental sustainability of digital libraries. The issues of sustainability should be considered in the context of the major factors influencing the lifecycle of information—from creation to the management, use/re-use, and disposal, when required, of information resource or tools and equipment, for example disposal of analogue information resources and also disposal of computing infrastructure and equipment, etc.

The conceptual model and the research framework serve to illustrate that a number of factors are responsible for, and contribute to, the different forms of sustainability of digital libraries. These factors may be related to the digital content and data, discipline and domain, user information behaviour, society and culture, ICT infrastructure, information design, legal and policy frameworks, and so on. Overall, the sustainability model can be used in association with various other information models to study the issues and challenges associated with the sustainability of digital libraries.

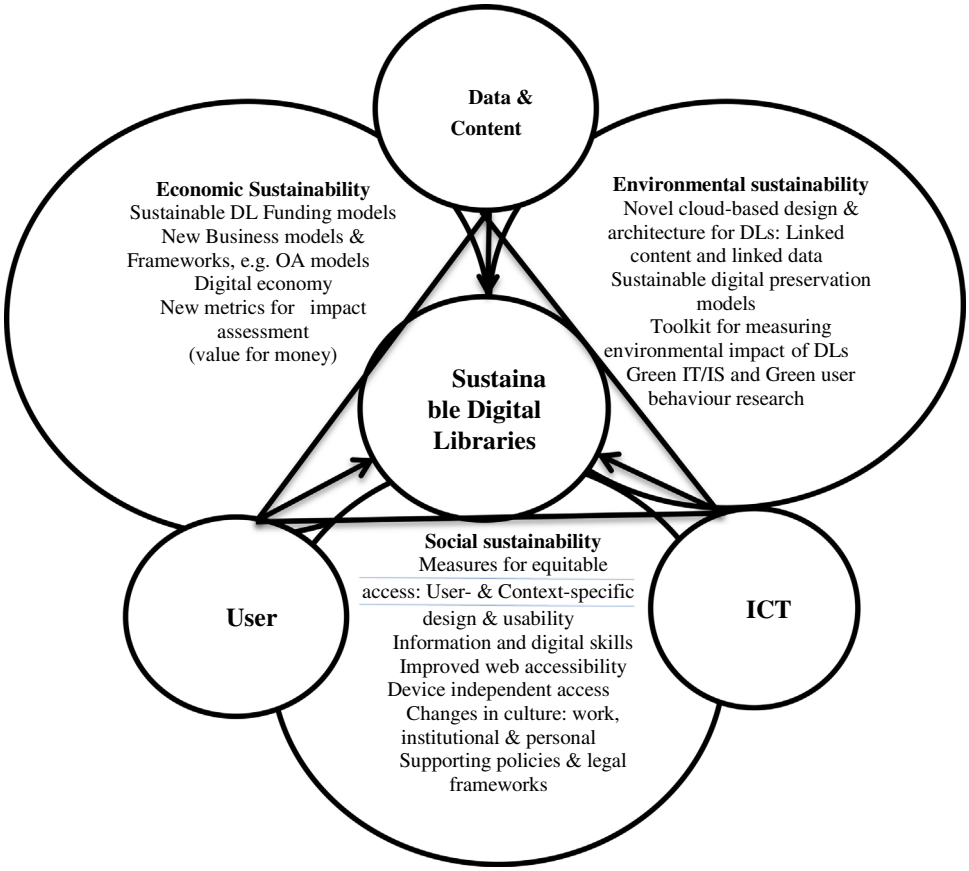

Fig. 1 A conceptual model and a research framework for sustainability of digital libraries

6.1 Influence of the research issues on different forms of sustainability

It may be noted that the various research issues related to one aspect of sustainability of digital libraries can have influence, positively or negatively, on the other forms of sustainability. As shown in Fig. 1, new funding and business models are needed for achieving the economic sustainability of digital libraries (see Sect. 7 for further discussions). However, such models should also support the social and environmental sustainability. If measured in simple economic terms, building a sustainable business model, especially in the business context, i.e. for-profit digital library services, does not necessarily aim to achieve the social sustainability goal of free and equitable access. Similarly, digital libraries may need to invest more resources to improve their design and usability if user- and context-specific digital library services are planned for everyone. As opposed to the commercial models, not-for-profit business models should aim to develop alternative metrics for measuring the impact and success of a digital library. Such measures may include contributions of the digital libraries in the overall sustainable development of a society in terms of development of a better workforce, a knowledge economy, a healthy society, etc. However, as discussed before, while such new business models and metrics can promote both the economic and social sustainability of digital libraries, these cannot be achieved unless appropriate legal and policy frameworks are developed to support such activities.

Green IT research shows that by adopting appropriate cloud computing technologies, digital libraries and information services can be more economically sustainable because of the economic and environmental benefits that such technologies can offer [3]. However, such economic and environmental benefits may have some adverse effects on the social sustainability of digital libraries unless appropriate legal policies and guidelines are developed that are suitable for specific business sectors. Similarly building of sustainable digital preservation models will promote the social sustainability of digital libraries because it will ensure equitable access to knowledge for the present and the future generations. However, building a sustainable digital preservation model needs more and long-term investment, and such investment should go hand in hand with the changing user needs and contexts—an area of HIB research according to the model in Fig. 1—the changing ICT infrastructure and technologies which is an area of research for the environmental sustainability, and so on. Thus overall, this model can help us better understand the various research issues related to the different aspects of the sustainability of digital libraries and their influence on each

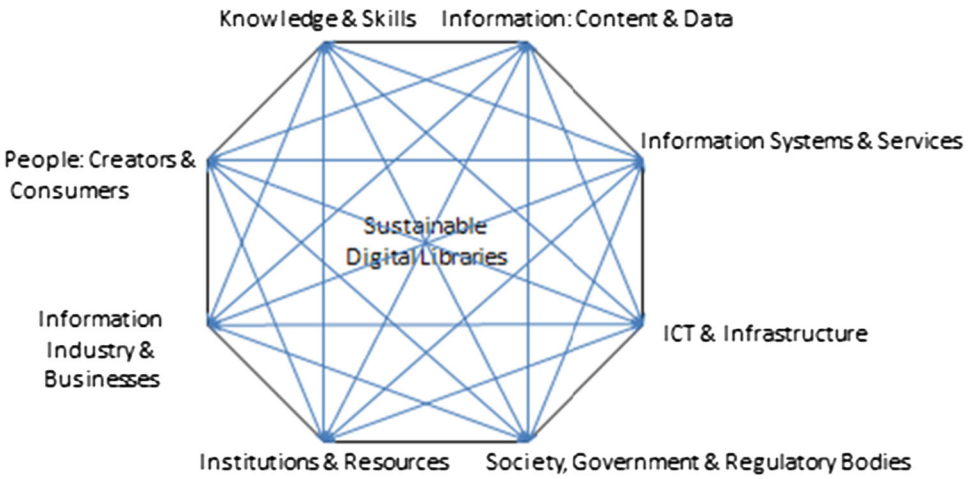

Fig. 2 A conceptual model for study of the sustainability of scholarly digital libraries

other. This is illustrated in the following section with examples drawn from a scenario of digital libraries of scholarly information.

7 Sustainability of digital libraries of scholarly information

This section discusses how the proposed conceptual model can be used to understand and study the ways in which various sustainability factors are related to, or influence, each other, and thus how the measures taken for achieving one form of sustainability can influence the other forms of sustainability. While Fig. 1 provides a generic model showing various research issues surrounding different forms of sustainability of digital libraries and information services, Fig. 2 shows a model representing different actors and their interactions towards the overall sustainability of digital libraries in the context of open access and digital libraries of scholarly information.

Figure 2 shows that there are eight major actors of a sustainable scholarly digital library model. Some of these actors are *People* or *Institutions* and thus are similar to those identified in the DLRM, but some like *ICT & Infrastructure* and *Knowledge & Skills* are more abstract, but they all have a major role in the overall sustainability of digital libraries:

1. *People: Creators & Consumers*: The creators and consumers of information are the actors. They belong to a society and are managed by the regulations, policies and practices of one or more government, institutions and communities of practice. They may belong to a specific institution ruled by a government and/or a regulatory body and its various policies.
2. *Institutions & Resources*: These are the actors as well as facilitators. Content creators and users belong to an institution, and in this regard they are the actors. Again resources for content creation, in terms of staff salary, research funding, etc., are provided through institutions and thus they are the facilitators. They also provide funding and management support for digital libraries that are used by their people (information users).
3. *Information Industry & Businesses*: Traditionally the information industry comprised the conventional publishers, distributors, online databases, aggregators, etc. However, in today's world a number of new players have entered the digital library and information marketplace such as various OA repositories and digital libraries, search engines and various specialized services like *Google Books*, *Google Scholar*, *Microsoft Academic Search*, etc., that facilitate access to information. Overall, they support and facilitate the various information creation as well as access processes.
4. *Knowledge & Skills*: These are the facilitators or key enablers. Disciplinary knowledge and appropriate skills—information skills, digital skills, writing & communications skills, etc., are essential for both the creation and use of information and data. They are also the intangible outcome of digital library services.
5. *Information: Content and Data*: These are the products of various activities performed by people in course of their research and scholarly activities, as well as various day-to-day activities of the businesses that they are engaged in. In the context of digital libraries these are the scholarly output (books, journal and conference papers, theses, reports, etc.) and datasets.
6. *Information Systems & Services*: These are designed and managed by people that belong to different institutions, and more often, in the information industry. In case of digital libraries these can be open-source or proprietary software systems. They facilitate access to, and use of, *Information: Content & Data*.
7. *ICT & Infrastructure*: They are the key enablers. They form the backbone of all digital library activities and

functions that are related to the creation as well as use of information—content and data. They are also the key enablers for digital library access and use.

8. *Society, Government & Regulatory Bodies*: The entire information industry and the service sector, and their various activities are governed, directly or indirectly, by a variety of government as well as international, regional and national bodies that formulate the necessary policies, funding mechanisms, standards, guidelines, etc.

It may be noted that some of the components and the related activities and functions are quite similar to the actors and functions identified by the previously developed digital library models like the 5*S* and the DLRM. However, these models do not explicitly address, and show the relationship among, the various sustainability issues.

The model in Fig. 2 shows that sustainable digital libraries reside at the intersection of the interactions amongst the different actors. In other words, sustainability of digital libraries can be achieved as long as we can maintain a balance amongst all the different actors and their underlying forces. Some of the actors perform specific functions or activities, while the others are the agents or facilitators for various activities, and some are the outcome of different actions. In some cases, actors may be the beneficiaries, for example, *People* and *Institutions* can be the creators as well as consumers of information. Some of the actors are facilitators as well. For example, *Governments*, *Information Industries* and *Institutions* are the actors because the information creators are part of them, but they are also the facilitators because they formulate various regulations, guidelines, standards and practices that control the processes of information creation as well as access and use.

The model shown in Fig. 2 can be used to demonstrate the various processes of creation, access and use of information in scholarly digital libraries. It can also be used to study the various factors that are responsible for the sustainability of digital libraries. Each vertex is linked to various other vertices based on the various activities involved in the creation, management and use of information. For example, the vertex *People: Creators & Consumers* and its linked vertices demonstrate that:

- People create information (content and data) using appropriate disciplinary and domain knowledge and skills (links amongst the *People—Information: Content & Data—Knowledge& Skills* vertices);
- The information creation process takes place by the people and the information industry (links amongst the *People—Information: Content & Data—Information Industry & Businesses* vertices);
- The information creation process requires resources (links amongst the *People—Information: Content & Data—Institutions & Resources* vertices);
- The information creation process is governed and facilitated by specific government or regulatory bodies (including national/regional/international bodies) (links amongst the *People—Information: Content & Data—Society, Government & Regulatory Bodies* vertices);
- The information creation process is facilitated by the ICT and infrastructure (links amongst the *People—Information: Content & Data—ICT & Infrastructure* vertices); and
- Access to information takes place through the specific information systems and services (links amongst the *People—Information: Content & Data—Information Systems & Services* vertices).

Similarly, the vertex *Information Systems & Services* is linked with various other vertices and it demonstrates that:

- People use information systems and services to access content and data (*People—Information Systems & Services – Information: Content & Data* vertices);
- People and the information industry and businesses work together to create, and sometimes manage, information systems and services (*People – Information Systems & Services – Information Industry & Businesses* vertices);
- People and specific institutions may create some information systems and services, e.g. institutional repositories (*People —Information Systems & Services—Institutions & Resources* vertices);
- People create information systems and services that are governed or influenced by specific regulations, for example the open-access regulations and policies of various funding bodies that have given rise to many institutional repositories (*People—Information Systems & Services—Society, Government & Regulatory Bodies* vertices);
- People create information systems and services that are facilitated by the available ICT and infrastructure (*People—Information Systems & Services—ICT & Infrastructure* vertices); and
- People use specific knowledge and skills to build and use appropriate information systems and services (*People—Information Systems & Services—Knowledge & Skills* vertices).

7.1 A sustainability model for OA digital libraries

For the purpose of illustrating how the model shown in Fig. 2 can be used, let us consider the recently introduced OA policies of various funding agencies, as discussed earlier in the

paper, and their implications for digital libraries of scholarly information. According to the model proposed in Fig. 1, the OA policies can be considered as the new funding policies to support OA publishing directed towards the economic sustainability of scholarly digital libraries. However, not every OA policymaker with the exception of some in the US, for example, the National Institute of Health, and the White House Office of Science and Technology Policy (OSTP) makes provision for the development and management of OA services like building repositories or digital libraries of OA content and data. In other words, costs for building and managing digital libraries of OA content and data are taken for granted by many OA policy makers.

Furthermore, the impact of these OA funding policies on various actors needs to be studied. For example, the OA funding policies will have a significant impact on (1) the content creators, i.e. researchers who publish research papers based on whether they can afford to pay APCs or their accessibility to research information because there will be a time lag depending on whether a research is published through the Gold or Green OA policy; (2) the publishing industry and journals, etc. because there will be a different set of rules based on whether or not authors are charged, and when and how the content is made available in the public domain; (3) the information service providers because universities and research councils may have to spend more money to build and manage OA services; (4) web search engines may be able to offer better and more values-added services (e.g. with citation data and linked research content and research data) when more and more research content and data are made available in the public domain; (5) the content users because of the specific OA policies chosen by the content creators (Green or the Gold route to OA), the mechanisms put in place for getting access to scholarly information—through a one-window search system or through specific institutional repositories, the corresponding embargo period imposed by various publishers, and so on. Furthermore, for this funding to be sustainable, some measures of the success or impact of digital library services have also to be developed. These can only be indirect measures, as discussed in Sect. 3, such as the contribution of the digital library in the creation of knowledge and skills. Different methods and techniques have to be developed for such indirect measures, and moreover these, being a long-time impact, can be assessed only after a reasonable period of time since the beginning of a digital library service.

As discussed earlier in this section, the model in Fig. 2 can help us understand this by looking at the various vertices and their links. Each of the vertices in Fig. 2 will have some kind of relationship with, or fore on, one another; and a sustainable digital library can be built only when an equilibrium is reached. For example, some kind of relationship or force exists between the *Information Industry* and the *Government*, *Institutions*, *Information creators*, *Information* (Content), *and Information Systems & Services*. To build sustainable digital libraries the new OA policies should redefine or counteract these forces amongst the different actors. Research shows that increasingly digital library users are using mobile devices for accessing information, and a large proportion of these accesses are search engine referrals [52,53]. From the sustainability of view, while platform- and device-independent access to digital information is ideal, this will have implications for the overall design of the digital libraries. Again, appropriate arguments for sustainable funding and better design and development of digital libraries can only be justified when appropriate evidences can be gathered through research as to how the digital libraries have, and can in future, improve the work and culture of people, businesses and society.

The OA policies will help us achieve the social sustainability of digital libraries because it will facilitate free access to scholarly information. However, this does not guarantee easy or equitable access to digital information. There may be several stumbling blocks for achieving this. One of the expectations of the research funding bodies is that output from the publicly funded research should be accessible to everyone in society. So, the obvious question is: how can we design digital libraries of different types of content and data that can support better and easier access to information for everyone in society? Furthermore, as more and more research content and data become available in the public domain, there will be needs for long-term preservation of content and data that will require more resources, and will be more technologically demanding—both in terms of disk space and appropriate tools and technologies. Thus, the OA policies should not only provide resources for alternative modes of publishing content, but also provide support for building and managing the appropriate information systems and services, and support the institutions and individuals (information creators) by providing appropriate ICT and infrastructure and other resources.

As more and more content and data become available in the public domain, appropriate measures have to be taken to build environmentally sustainable digital libraries and preservation systems. The model in Fig. 2 can help us explain this. Over the past few years environmental issues have taken a major place in business and policymaking in every government, industry and institution. The OA digital libraries will make more demands for ICT energy, and hence we need to build various techniques and tools for measuring the environmental impact of digital libraries. Some environmental sustainability measures may come from the use of energy-efficient hardware, software and network infrastructure, but a large part of it will come from the end-user ICT and information behaviour vis-à-vis the efficiency of the design of specific digital libraries. For example, the less time and more

energy-efficient device (thin client) that a user can use to access and use information from a digital library, the more energy efficient, and thus more environmentally sustainable will be the digital library. Thus, a variety of related research issues need to be studied to build green information services, and the proposed model can guide us to identify and focus on such research issues. According to the model in Fig. 2, it will be in the interests of the *Government*, *Institutions* and individual users (*People*) to use appropriate *ICT* to build more energy-efficient and therefore green *Information Systems and Services*. Research shows that cloud computing technologies have some promises for the economic and environmental savings [3,9], but more research is required to build cloud architecture for digital libraries and digital preservation systems that not only provide better and easier access, but also provide adequate protection for various privacy and security issues, an area of concern for several actors in Fig. 2, such as *People*, *Institutions, Information Industry & Business* and *Government*.

8 Conclusion

To build sustainable digital libraries, attention should be paid to all the three areas viz. economic, social and environmental sustainability. The conceptual model presented in this paper shows that a number of stakeholders and factors are involved in today's world of digital libraries. The proposed model can be used in conjunction with other digital library models. For example, the proposed model can be used in conjunction with the different functionality domain concept maps of the DRLM to study how a specific functionality of an actor—an end-user or a digital library manager, or a specific action, for example management and preservation of an information object, can influence—positively or negatively, the different forms of sustainability. The *economic sustainability reference model*, discussed in Sect. 3.2, shows that the economic sustainability challenges of digital preservation should be considered in the context of the overall economic environment within which the preservation activities take place, as well as the specific strategies for digital preservation, and the risks and benefits in the context of the concerned content and various actors. Overall, the DRLM and the *economic sustainability reference model* for digital assets implicitly mentioned various factors and their implications for sustainability. These models have not considered the three dimensions of sustainability per se, and the various research challenges and their implications for each form of sustainability; and this is what is unique in the model proposed in this paper. The models proposed in this paper can be used as a research framework to study various sustainability factors in the context of different types of digital libraries to explicitly identify the role, and influence, of various actors and their interactions in the context of the overall sustainability of digital libraries; and this calls for an integrated research approach.

Nathan [54] comments that information science, human–computer interaction, and participatory research approaches can help citizens develop practices that reduce negative ecological, economic, and social impacts of our information practices. The models proposed in this paper can be used as a research framework to understand and study the various actors and their interactions that contribute to the economic, social and environmental sustainability of digital libraries.

Reducing end-user ICT energy costs and promoting Green user behaviour [9] of individual users, and society at large, can play a big role in achieving the environmental sustainability of digital libraries. The sustainability models proposed here suggest that all the stakeholders as well as the technologies, knowledge, skills and culture of people should work in harmony to achieve the economic, social and environmental sustainability of digital libraries. Overall, the model can serve as a starting point for future research and development with a holistic view of digital libraries, and the various factors that have implications for all the three forms of sustainability.

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