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ESCUELA INTERNACIONAL DE DOCTORADO

Software Requirements for Energy Efficiency in Information Systems: Catalogue and Applications

Requisitos Software para la Eficiencia Energética en los Sistemas de Información: Catálogo y Aplicaciones

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Esta tesis se presenta de acuerdo con el Real Decreto 99/2011, de 28 de enero y el reglamento por el que se regulan las enseñanzas oficiales de doctorado de la Universidad de Murcia (aprobado en Consejo de Gobierno de 27 de enero de 2012 y modificado en Consejos de Gobierno de 26 de julio de 2013, 4 de octubre de 2013, 26 de marzo de 2014, 30 de abril de 2015, 20 de diciembre de 2018 y 15 de marzo de 2019). La tesis cumple con lo indicado en las normativas mencionadas.

Más información en: https://www.um.es/web/eidum/contenido/normativa

A mis padres

I used to dream

I used to glance beyond the stars

Now I don’t know where we are

Although I know we’ve drifted far

Michael Jackson’s Earth Song, 1995

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Abbreviations

AKA	Also Know As
CAT-SUST	Catálogo de Sostenibilidad
CARM	Comunidad Autónoma de la Región de Murcia
DSR	Design Science Research
GUI	Graphical User Interface
GSS	Green Software System
GHGE	Greenhouse Gas Emission
IDE	Integrated Development Environment
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IS	Information System
JCR	Journal Citation Reports
OLED	Organic Light-Emitting Diode
PHR	Personal Health Record
RE	Requirements Engineering
SDG	Sustainable Development Goal
SI	Sistema de Información
SIREN	Simple Reuse of Software Requirements
TI	Tecnologías de la Información
TIC	Tecnologías de la Información y Comunicación
TFT	Thin-Film Transistor
TW	Terawatt
UN	United Nations

Contents

Resumen

REQUISITOS SOFTWARE PARA LA EFICIENCIA ENERGÉTICA EN LOS SISTEMAS DE INFORMACIÓN: CATÁLOGO Y APLICACIONES

Las tecnologías generan riqueza y bienestar en las modernas sociedades actuales [1]. Su uso está muy arraigado [2] y presente en multitud de ámbitos cotidianos como la salud, la banca electrónica y la prensa [3]. A pesar de la gran aportación que hace la tecnología a la comunidad, la concienciación en el gasto energético no está tan extendida entre los usuarios [4]. Además, la ubicuidad que presentan los dispositivos móviles, incrementa su utilización y aumenta la demanda de energía. En general, el uso que se hace de los dispositivos tecnológicos es despreocupado en términos energéticos [5].

La producción de energía tiene un gran impacto en el medio ambiente cuando proviene de fuentes no renovables [6]. Existe la creencia errónea de que el gasto unitario de un dispositivo electrónico supone un nivel de contaminación tan bajo que es despreciable. A nivel local puede ser cierto pero el elevado número de aparatos electrónicos que funcionan actualmente en el planeta (hay más números móviles que habitantes en los países) hace que el impacto sea significativo [7, 8]. Esta situación lleva a pensar que el comportamiento individual es clave para lograr un uso responsable de la energía. Además, la situación alarmante del medio ambiente acelera la consideración de la eficiencia energética como un atributo de calidad en la tecnología, reduciendo su repercusión en el planeta.

El impacto que genera la producción de energía para el uso de la tecnología es muy importante a nivel mundial [9]. El sector TIC generó en 2016 un total de 196 Mt de CO_2 que fueron arrojados a la atmósfera. Esta cantidad podría crecer en un 16% en 2040 [10]. Por otro lado, están surgiendo importantes iniciativas para reducir las emisiones y contribuir a un planeta más verde. En 2015 un total 10 TWh provenientes de energías renovables fueron gastados por

las principales compañías de Estados Unidos. Esta cifra se incrementó en 18 TWh en 2018[1]. Muchas ciudades del planeta se abastecen hoy día con el 100% de energías de fuentes renovables, algunos ejemplos: Burlington (Estados Unidos), Reykjavik (Islanda) y Basilea (Suiza)[2]. A pesar de las dificultades causadas por la crisis mundial de la pandemia de COVID-19, existe cierto optimismo sobre la aceleración de la transición hacia la producción de energía sostenible con el desarrollo de las tecnologías limpias[3].

Dada la situación actual de deterioro del medio ambiente surge la necesidad de ofrecer soluciones tecnológicas que sean más sostenibles. Tradicionalmente se ha trabajado en producir energía más ecológica, así como en generar dispositivos hardware que requieran de menos energía para funcionar. Sin embargo, el software, que gobierna el funcionamiento del hardware también tiene un papel importante de cara a reducir el consumo energético de la tecnología. En esta tesis doctoral se planteó la siguiente hipótesis.

La reducción del consumo de energía que un sistema software genera en un sistema hardware puede alcanzarse mediante la reutilización de un catálogo de requisitos de software.

Los requisitos en los proyectos software son fundamentales a la hora de definir la solución tecnológica a un problema determinado. El nivel de detalle de una especificación de requisitos software varía en función del tiempo y esfuerzo que se le dedica en las etapas iniciales del proyecto. Es muy frecuente que la eficiencia energética del software no sea considerada en el ciclo de desarrollo. Ante esta situación surge la necesidad de definir un artefacto que promueva el uso de los requisitos sobre consumo energético de los sistemas de información (SI).

Los requisitos en sostenibilidad comprenden el conjunto de características del software que generan un cambio en el consumo energético de un sistema hardware. Dentro del ahorro energético que se puede obtener a través del software se definen dos perspectivas principales, Green in Software y Green by Software [8]. En la primera de ellas se pretende que el proceso de desarrollo del software, así como el producto software, sea más eficiente desde el punto de vista

[1] https://www.epa.gov/greenpower/green-power-partnership-top-30-local-government

[2] https://www.cdp.net/en/articles/cities/over-100-global-cities-get-majority-of-electricity-from-renewables

[3] https://www.iea.org/news/reaching-energy-and-climate-goals-demands-a-dramatic-scaling-up-of-clean-energy-technologies-starting-now

energético. Con el segundo término se pretende definir que un sistema existente se convierta en verde, requiriendo de menos cantidad de energía, ya que ha sido complementado con un nuevo software que lo hace más eficiente.

No es inmediato comprender cómo un código software puede generar un mayor o menor consumo en el sistema. A modo de ejemplo, las tonalidades de color mostradas en una interfaz gráfica pueden suponer una variación importante en el consumo energético del monitor. La tecnología de pantalla thin-film transistor (TFT) se caracteriza por cubrir cada pixel con un obturador para tapar la retroiluminación. Con ello se logra mostrar los colores oscuros de la imagen. Por otro lado en la tecnología organic light-emitting diode (OLED) se apaga el pixel para mostrar el color negro, permitiendo mostrar tonalidades más oscuras. Se puede intuir que con tecnologías TFT es mejor utilizar colores claros para evitar mover el obturador del pixel y con ello gastar más energía de la que se requiere de base para el funcionamiento del monitor. Por el contrario, en tecnologías OLED es mejor utilizar tonalidades oscuras en las interfaces de usuario que evitan encender el pixel. Este sencillo ejemplo sirve para ilustrar cómo la toma de decisiones tan básicas como es el color de la interfaz impactan en el consumo energético. En la mayoría de casos no es sencillo abordar los requisitos de sostenibilidad, ya que la tecnología en la que se va a emplear el software puede ser muy diversa.

La producción y consumo de la energía es un objetivo prioritario por las Naciones Unidades (UN). En la Agenda de 2030 para el Desarrollo Sostenible se proponen un total de 17 objetivos a cumplir entre los gobiernos de los países. El fin es promover un crecimiento respetuoso con el medio ambiente. En particular, el objetivo número 7 se centra en la producción de energía asequible y no contaminante. En la actualidad, se observa que la energía está más accesible en los países más pobres y su producción con fuentes renovables se está generalizando. En este objetivo destacan los siguientes datos: 1) la energía es el factor principal que impacta en el cambio climático y representa el 60% de las emisiones de gases de efecto invernadero a nivel mundial; 2) en 2015 el consumo de energía de fuentes renovables fue del 17,5%[4].

Las principales contribuciones de la investigación realizada durante la etapa predoctoral son las siguientes: (1) exponer la situación real de la aplicación de medidas y hábitos de sostenibilidad en el software; (2) detectar las lagunas y dificultades que afronta un ingeniero informático a la hora de desarrollar software sostenible; (3) proponer un artefacto que permita facilitar la

[4]https://sdgs.un.org/es/goals

tarea de generar software con aspectos de eficiencia energética; (4) validar el artefacto.

En primer lugar se estudió la literatura sobre sostenibilidad en tecnologías de la información (TIs) con parámetros bibliométricos. Los análisis de la literatura basados en parámetros bibliométricos se conocen como estudios bibliométricos. No están muy extendidos en la literatura científica actualmente, y se concentran básicamente en revistas especializadas en cienciometría y bibliometría. Al observar las tendencias, los valores de los parámetros y gráficas es posible conocer rápidamente la situación actual de un determinado campo de estudio. En el trabajo realizado se utilizó la base de datos Scopus para buscar los artículos. La construcción de la cadena de búsqueda fue extensa, ya que la nomenclatura que se utiliza en este ámbito de la literatura es muy variada. Se analizaron los parámetros bibliométricos generados a partir de un total de 4.398 artículos. Como resultado de este estudio se observó que existe una tendencia alcista en el número de publicaciones por año. El hecho de que el número de publicaciones aumente con los años refleja la importancia que está adquiriendo la sostenibilidad tecnológica. Los artículos que se publican en esta temática son en su mayoría artículos de congreso, lo que puede ofrecer una comunicación más directa entre autores de cara a proponer soluciones en el corto plazo [11].

Un conjunto de empresas de desarrollo software en la Región de Murcia fueron seleccionadas con el fin de conocer los hábitos y prácticas de los trabajadores en software sostenible. El objetivo era analizar las medidas adoptadas en sostenibilidad durante el desarrollo de software y los mecanismos empleados para producir software sostenible. Se escribió una encuesta sobre software sostenible con la finalidad de recabar la información de los profesionales. En la encuesta se presentaron diversas alternativas sobre eficiencia energética en el ciclo de vida del software. Los hábitos y prácticas en software sostenible se contrastaron con la literatura. Con el fin de dar soporte institucional a la actuación se solicitó la participación de miembros de organizaciones públicas como la Dirección General de Medio Ambiente y la Dirección General de Informática Corporativa de la Comunidad Autónoma de la Región de Murcia (CARM). Además, se gratificó a los participantes con un diploma en el que se mostraba su interés por colaborar en iniciativas sostenibles tecnológicas en el ámbito de la empresa. Entre los principales resultados destacó que el reuso de código, de requisitos y de especificaciones, así como, el testeo y la integración continua fueron las prácticas que los profesionales consideraron fundamentales para generar software sostenible. Las líneas de producto software, el big data o la minería de datos, junto con el internet de las cosas y la realidad virtual y aumentada fueron las que menor impacto se consideró que podía generar en el software sostenible [12].

Ante los resultados obtenidos en la encuesta se puso de manifiesto la importancia que tiene para los profesionales del software el reuso de requisitos en el desarrollo de software sostenible. La principal contribución de la tesis doctoral es un catálogo de recomendaciones que sirve de guía en el software energéticamente eficiente. El artefacto se nombró como Catálogo de Sostenibilidad (CAT-SUST). CAT-SUST se organizó por secciones teniendo en cuenta el estándar IEEE 29148. Cada una de las recomendaciones fue propuesta en base a la literatura y validada con mediciones de consumos de energía. Para la realización del catálogo se analizaron un conjunto de sistemas de Carpeta Personal de Salud (del inglés Personal Health Record, PHR), que son: HealthVet, HealthVault, NoMoreClipBoard, PatientsLikeMe y Health Companion. Se definieron un conjunto de tareas representativas en los PHRs, que se realizaron durante la medición de consumos de potencia en los principales componentes de un PC (disco duro, procesador, tarjeta gráfica, monitor y fuente de alimentación). Posteriormente, se analizaron las interfaces gráficas de usuario (GUI) de los sistemas mencionados con el fin de estudiar el impacto que producen en el consumo energético cuando se implementan las recomendaciones propuestas en CAT-SUST. En el catálogo mencionado, cada recomendación consta de un identificador, una descripción y un componente de validación, que puede ser una tarea validadora de la recomendación o una cita bibliográfica (ver artículo número 3 del compendio de publicaciones) [7]. En diversos trabajos posteriores, incluidos algunos de ellos en esta tesis como *Artículos en Revistas JCR no Consideradas en el Compendio de la Tesis*, se estudió de nuevo el impacto de las recomendaciones en el consumo energético. En los trabajos mencionados se evaluó, además, la usabilidad de los PHRs. Se emplearon para ello los principios de usabilidad de los autores Alan Dix [13] y Jakob Nielsen [14] como heurísticas. Los resultados de las evaluaciones de usabilidad se compararon con los consumos de energía con el fin de detectar si un sistema con un resultado en usabilidad alto puede requerir al mismo tiempo menos energía para su funcionamiento [15].

Un catálogo como CAT-SUST facilita la tarea al desarrollador de cara a tener una guía para construir software sostenible. En la literatura no es muy frecuente encontrar artefactos con el mencionado fin [16]. Además, la variabilidad de la tecnología hace complicado generalizar su uso. No obstante, en la actualidad existen diversas soluciones tecnológicas que permitirían reducir este problema que se puede dar inicialmente. A modo de ejemplo se podría utilizar un entorno de desarrollo integrado de software (IDE) provisto de inteligencia artificial que permita proponer estructuras de código que sean más sostenibles con el hardware a utilizar. También se plantea la posibilidad de que en el momento de instalar un software en un sistema determinado se pueda realizar una compilación parcial condicionada que asuma aspectos de sostenibilidad. La compilación parcial permitiría adecuar las características del software al sistema hardware a utilizar con el fin de que sea más eficiente energéticamente.

Se plantea la posibilidad de realizar un experimento con el que demostrar que para un hardware determinado, el software puede variar el consumo energético de forma destacada. En esta línea se podría desarrollar un compilador que determine las instrucciones a ejecutar en función del hardware en el que la aplicación se va a usar. El IDE también podría sugerir el código fuente que genere un menor consumo en el hardware.

Con los resultados obtenidos en la presente tesis se ha demostrado que a través del software es posible reducir el consumo energético en un determinado hardware. Bien es cierto que la solución planteada es limitada. No obstante, se continuará trabajando en esta línea de investigación para enriquecer el catálogo, proponiendo además un modelo de auditoría de la sostenibilidad energética en función de las recomendaciones implementadas en los sistemas software.

1 Introdution

Information and Communication Technologies (ICT) are rooted in modern societies [2]. They create wealth and welfare [1], and can be found in several areas of everyday life, such as health, financial or media sectors [3]. Despite their important contribution to the community, their massive usage is not accompanied by a widespread energy awareness [4]. In most of cases electronic devices are used carelessly in terms of energy consumption. Moreover, the ubiquity of the information systems (IS) increase their use and, therefore, the demand of energy [5].

Energy production has a major impact on the environment when non-renewable resources are used [6]. There is a mistaken belief that the use of a single electronic device generates such a small amount of pollution that it is negligible. This idea might be truth from a local perspective. However, the high number of electronic devices on the planet makes the total impact significant [7, 8]. Thus, individual behaviours are key to achieve a responsible energy use. In this vein, energy efficiency is gaining popularity lately as a quality attribute of the ISs, making users do a more considerate use of energy.

ICTs release big amounts of CO_2 into the atmosphere [17]. A total of 196 Mt CO_2 were generated in 2016 because of the ICT sector [10]. In addition, the Greenhouse Gas Emissions (GHGE) coming from ICTs are expected to raise 14% of the levels in 2016 by 2040 [18]. Major changes to address the current situation are necessary not only from individuals but from the governments too [19]. Only the power and heavy industry together generate the 60% of the emissions nowadays, and these levels could increase to nearly 100% in 2050[1]. It is not surprising that today the ways of life of the past are being questioned[2]. It is worth noting that the impacts of the current COVID-19 pandemic has lead to an important decreasing in the estimates. As an example, it is expected the global energy demand had decreased by 5%

[1]https://www.iea.org/reports/energy-technology-perspectives-2020
[2]https://www.dw.com/en/what-will-be-the-future-of-tourism-in-venice/a-53823135

in 2020. Moreover, energy-related CO_2 emissions could have disminished by 7% in the same year[3].

The UN elevated the international commitments from global stakeholder to grant access to affordable, reliable, sustainable and modern energy supplies all over the world. The 2030 Agenda for Sustainable Development of the UNs consists of a collection of 17 Sustainable Development Goals (SDGs). All of them are an urgent call to all countries tackling climate change and preserving the environment[4]. Particularly in the 7th SDG, the shares of renewable energy consumption should remarkably scale, increasing simultaneously the efficiency use of energy [20]. The impact that technology generates in the environment is remarkable worldwide. The power generated from renewable resources and spent by the technology companies in the EEUU had increased over the last few years. About 10 TWh were spent in 2015, and this amount of power increased to about 18 TWh in 2018[5]. Nevertheless, important challenges are being accomplished lately with the supply of energy 100% from renewable sources in megalopolis such as Sydney[6]. In addition, energy saves are very important given the alarming situation of the planet. The European Strategic Energy Technology claims that a 80% reductions in GHGE from the energy production sector should be achieved by 2050 [21]. It is observed that ICTs impact on future of global energy consumption [22]. ICTs can reduce pollution by increasing energy efficiency [9]. However, the net benefits of ICTs in the environment are not always guaranteed [23]. Technological inefficiency becomes a major barrier to achieve sustainability [24]. The use of ICTs to reduce energy consumption may not be enough. In order to broaden the objectives in energy consumption by using technology, it is noted that software can also be a key factor to be taken into account[7]. In addition, as the UNs say "green is clean", this goal can be achieved by adopting green technologies [25].

Energy efficiency in technology can be achieved from either a hardware or software perspective. In the former, electronic designs are carried out by minimising as much as possible the amount of energy to operate. In the latter, the aim is to design the software in such a way that governing the operation of the hardware achieves the lowest possible consumption. In addition,

[3] https://www.iea.org/reports/world-energy-outlook-2020
[4] https://sdgs.un.org/es/goals
[5] https://www.epa.gov/greenpower/green-power-partnership-top-30-local-government
[6] https://www.euronews.com/living/2020/07/01/city-of-sydney-now-runs-on-100-renewable-energy
[7] https://www.networkworld.com/article/2861005/energy-aware-software-design-can-reduce-energy-consumption-by-30-to-90.html

the aim is also to produce the lowest possible energy expenditure during software development. The aforementioned ideas define the concept of sustainable software. The literature proposes a set of 2 definitions of sustainable software, green in software and green by software. The former focus on building software and the process of developing software that is more energy efficient. In the latter attention is paid on achieving energy efficiency via software use [8].

Sustainable software arises with the aim of reducing energy consumption, as it has been observed that software can influence energy needs. There are several factors that determine the impact of software on energy consumption. Currently, ISs that have addressed energy efficiency aspects from a software perspective are not very common. However, the dissemination of energy efficiency achieved through software is gaining momentum in the literature. The Karlskrona Manifesto is a starting point for defining sustainable software from the Software Engineering perspective. It lists a number of principles and commitments to be taken into account to improve software sustainability. A total of 5 dimensions are defined: Individual, related to the perseverance of human capital; Social, the maintenance of solidarity and services in social communities; Economic, the generation of capital and added value; Environmental, the improvement of welfare with the protection of natural resources; and, finally, Technical, the guarantee of the longevity of ISs and infrastructures and their appropriate evolution [26].

Software quality can have direct implications for energy consumption. Quality can be classified into several factors such as correctness, reliability, efficiency, integrity, usability, maintainability, flexibility, testability, portability, reusability and interoperability [27]. The research of this thesis postulated that a system with high software quality characteristics can be energy efficient at the same time. Among the different quality attributes that can affect the energy consumption of software, emphasis was placed on usability. The reasons for selecting usability were due to the fact that usability enables systems to be used comfortably by users [28]. In addition, usability has been rated as one of the most important factors influencing the acceptance of systems [29]. Applications with high usability features allow tasks to be performed more quickly [30].

Energy efficiency in software must be at the heart of debate in order to achieve clean technology with the least possible damage to the environment. Indeed, population growth will generate a high demand for information in the future, further degrading the environment. Energy consumption must therefore be carefully considered in ISs. As an example, the healthcare is one of the critical sectors that will face major challenges in terms of energy efficiency. The existence of devices such as wearables, which are very present today, illustrates how modern information societies demand more technology and availability of information everywhere. Another example are the personal health records (PHRs). They are electronic health systems, which allow users to keep track of the evolution of the diseases they suffer from. PHRs allow medical data to be stored by the patients themselves. These systems are being implemented in many health services. Although they are not widely known, studies indicate a predisposition on the part of users to adopt the aforementioned technology [31]. The number of users grew rapidly and exceeded 31 million members in 2013 [32]. Some of these systems were very popular by the end of 2020. As an example, in Kaiser Permanente[8] there were more than 12.4 million registered users, more than 3.25 million in HealthVet[9], and more than 0.8 million users in PatientsLikeMe[10]. PHRs were used as a case study in this research to evaluate the energy efficiency of ISs.

The papers submitted to the thesis compendium are in line with the research on sustainable software. In this regard, a study of the literature concerning sustainable technologies was performed. This analysis allowed to know the current status of the aforementioned topic in terms of bibliometric parameters. Variables such as number of publications, tendencies in the number of papers through the years or the cooperation between authors from different institutions and countries were studied. Moreover, they exposed that the research topic is increasingly popular. The results of this study were published in the journal named Sustainable Development, JCR Q1 [11].

In addition to the aforementioned work, information on the current situation of sustainable software in technology companies was extracted through a survey. A relevant amount of workers from a collection of targeted companies were offered to complete a survey. The respondents showed interest in the topic of research. However, there was not a clear idea on what sustainable software is and how to take its considerations into the work they do daily. The results of the survey were published journal named Applied Science, JCR Q2 [12].

The PHRs HealthVet, HealthVault, NoMoreClipBoard, PatientsLikeMe and Health Companion were used as sample software in an empirical study. They allowed to identify which

[8]https://about.kaiserpermanente.org/who-we-are/fast-facts
[9]https://www.myhealth.va.gov/mhv-portal-web/webusers
[10]https://www.patientslikeme.com/about

software factors influenced the energy consumption of the different components of a PC (i.e.: hard disk drive, processor, graphics card, monitor and power supply). The analysis of the power consumption, together with the characteristics of the graphical user interfaces (GUIs), allowed to build a collection of recommendations to develop sustainable software (CAT-SUST). The purpose of the CAT-SUST artifact was to promote and help technicians producing sustainable software. CAT-SUST can be applied to any kind of IS, and employed for audit purposes. The results of this study were published journal named Journal of Cleaner Production, JCR Q1 [7].

Finally, usability assessments of the GUIs in the aforementioned systems were carried out. The correlations between the usability evaluations and the energy consumption measurements were studied. This analysis allowed to perform a preliminary validation of the CAT-SUST artifact. A total of 2 papers were published with the results of the experiments in 2 high impact factor journals. They are exposed at the beginning of this dissertation as *Papers in JCR Journals not Considered in the Thesis by Compendium* [15].

The reminder of the dissertation is organised as follows. Section 2 presents the main hypothesis of this study. In Section 3 the thesis objectives are described. In Section 4 the research method followed is introduced. In Section 5 the papers that make up the thesis by compendium are shown. Finally, in Section 6, conclusions and future work are drawn.

2 Hypothesis

Quality is an important factor in the development of software applications. High quality software offers advantages, which are key in the evolution of technology. The budget and time are limited when it comes to tackling a software project. Therefore, the allocation of resources is key to achieving a solution that meets the demands of the stakeholders in the best conditions.

Energy efficiency is gaining popularity in software systems. In fact, software that generates low hardware power consumption is considered quality software [33]. This feature stands out between other important software quality factors, such as usability, functionality, security, accessibility, etc. However, studying the energy consumption in the components of a host machine with a running software system is a complex task. Traditionally, the focus has been on hardware to reduce energy consumption. However, software can also contribute significantly to energy consumption.

The main problem concerning the energy consumption that software generates in the hardware is the variety of technologies available when developing a system. Achieving hardware power reduction through software is difficult in general. Each energy tradeoff in software is designed for a particular technology, which makes sustainable software a very broad technical issue to deal with. For example, depending on the technology of the monitor, it is better to use in the GUI white tonalities (i.e., TFT) or dark tonalities (i.e., OLED) to save energy. The number of lines in an algorithm can also make the code more energy efficient. However, if the software and hardware technologies are clearly determined in the system to be built, technicians can follow specific sustainable software recommendations. In this way, a software system with reduced energy consumption might be achieved. Currently, collections of requirements for producing sustainable software are very scarce [16, 34]. It is therefore important to devote more research efforts to achieve this goal.

This thesis studied the impacts on the energy consumption of the main components of a PC given the characteristics of the GUIs of the PHRs. To better understand the scope of the study, the following hypothesis was proposed.

H. *Reducing the energy consumption a software system generates in a hardware system can be achieved through the reuse of a software requirements catalogue.*

3 Goals

There is currently a significant gap on how to address energy consumption features in software projects [35]. The software development cycle and the software product often lacks energy saving aspects. Therefore, the following main objective was set.

> ***G.1.*** *Define an artifact to make it easier for software developers to build energy-aware software.*

This objective was divided into smaller, more manageable objectives in order to organise the research work. The sub-objectives are as follows.

G.1.1 *Knowing the current management of the development processes for Green Software Systems (GSSs)*

The definition of this objective allowed to know the current situation regarding the management of software processes in the technology industry. Methodologies ranging from prescriptive to agile can be applied according to the characteristics of the software project. However, in both cases, sustainability aspects are neglected. Keeping this objective in mind, it was possible to address the goal of the research in a more precise way.

G.1.2 *Defining Requirements Engineering (RE) artifacts for GSSs*

This thesis is based on the idea of requirements reuse. To address the gap detected in the literature, an artifact was proposed . It consists of a catalogue with recommendations for the production of green software (i.e.: green in software). The aforementioned catalogue aims at facilitating the reuse of requirements as in the case of the Simple Reuse of Software Requirements catalogue (SIREN). CAT-SUST allowed to address the main objective to be achieved, which is to make it easier for technicians to develop sustainable software [7]. A collection of recommendations for sustainable software should be a common artifact frequently consulted. Further work would lead to a more complex set of recommendations.

G.1.3 *Testing of requirements to the green aspects of a software system*

The aforementioned recommendations were validated with several basic empirical studies. The results showed that the implementation of the recommendations can lead to a decrease in the power consumption of the main PC components.

G.1.4 *Validation of proposals for greenability, in relation to the above objectives*

To generalise the results, several experiments were carried out in which, in addition to considering the energy efficiency of the software, the usability of software systems was evaluated. The conclusions of the aforementioned experiments were analysed, allowing the artifact to be validated [15].

4 Methodology

In the work presented in this dissertation the research tasks were carried out using Design Science Research (DSR) [36]. This method was employed to define the problem, organise the research and set an artifact with which to address the detected problem. From this research it was observed that in Software Engineering it is not usual to deal with the aspects of energy consumption. Prioritising the time and cost of the software solution undermines the attention paid in projects to the technical characteristics that include energy consumption. In addition, there is a general lack of knowledge on how to produce sustainable software. In this research the software development processes were analysed. Furthermore, an artifact was proposed in order to assist in the software development cycle and reduce energy consumption. The artifact resulting from this research was validated by carrying out the following steps: 1) description of the objectives to be pursued; 2) selection of the evaluation protocol; 3) setting the characteristics to be evaluated; and 4) specific planning of the evaluation. The main work and methods used during the doctoral phase are described below.

First, a quantitative analysis of the literature [37] allowed us to observe the academic relevance of the research topic introduced in this dissertation. A bibliometric study [38] was conducted to analyse the current status of publications on sustainable technologies. The aforementioned literature review provided the state of the art on the objectives of the thesis from a bibliometric perspective. Bibliometric studies provide researchers with an overview of the relevance of a topic. A wide variety of bibliometric parameters are analysed in these studies. The aspects covered range from descriptive analysis, author output, journal productivity, scientific collaboration, author citation analysis and journal citation analysis between others [11].

In addition, an empirical study was carried out to meet the objectives of the thesis. Empirical studies can be divided into 3 main types, which are experiment, survey and case study [39]. The empirical study carried out consisted of a survey. The Transtheoretical Model (aka Stages of Change Model) [40] allowed to categorized the respondents according to their willingness to keep or change habits and practices on sustainable software. Technicians from technology companies in the Region of Murcia sent their responses, which made it possible to gather first-hand information on the current situation.

It is worth noting that several strategies were followed to attract more participants to complete the survey [41]. On the one hand, the survey was available online, allowing participants to complete it at any time [42]. Members from 2 public institutions, one of them related to ICTs and the other one with the environment, both from the CARM government, were invited to support the research. Moreover, leading members in corporate social responsibility at the University of Murcia and CARM agreed on cooperating. Their contribution consisted in signing diplomas to the participants, recognizing their interests on sustainable software. Some results of the survey, highlighted the reuse of software requirements as one of the most recognized habit to achieve sustainable software. In addition, testing and continuous integration were the practices that technicians considered fundamental for sustainable software. On the contrary, software product lines, big data or data mining, along with the internet of things and virtual and augmented reality were seen as having the least impact on sustainable software [12].

Since the reuse of code, requirements and technical specifications was the factor that the technicians considered most important to achieve software energy efficiency, the topic of investigating requirements in sustainable software was addressed. It is worth noting that software requirements reuse was a pioneering idea of researchers from the Software Engineering Research Group at the University of Murcia. In particular, a requirements engineering method was proposed to make it easier the elicitation of requirements through reuse (SIREN). The method provides with a reusable requirements repository, a spiral requirements engineering model and a set of requirements document templates [43]. SIREN was employed as a strategy to obtain a collection of recommendations aiming at promoting the reuse of sustainable software requirements.

An empirical study was conducted with the aim of responding to the main finding observed in the previous study. The empirical study carried out consisted of an experiment. The energy consumption data of the main components of a PC (i.e. hard disk, processor, graphics card, monitor and power supply) were studied. For this work PHRs were used as a case study [44]. A set of typical tasks were selected to represent a typical use of the aforementioned systems

[45, 46, 31]. During the performance of the tasks in the PHRs, the amount of energy was measured by means of probes connected to the aforementioned components. This work allowed to study the characteristics of the GUIs and their impact on energy consumption. As a result, a catalogue of recommendations was obtained that covers the reuse of requirements in sustainable software [7, 15].

5 Full copy of the papers

This section presents the papers that have constituted the compendium of the doctoral thesis. The PhD programme in Computer Science at the University of Murcia based on the Royal Decree 99/2011 allows this form of presentation of the thesis dissertation.

Sustainable technologies are a means that can guarantee energy efficiency with less impact on the planet. The articles of the compendium are related by goal number 7 of the 2030 Agenda for Sustainable Development. The study of the relevance that sustainable technologíes have on the literature was addressed. The first paper is a bibliometric study on sustainable technologies. The article was published in 2019 in the journal Sustainable Development, Q1 and with an impact index of 4.082 [11]. In addition, the current situation in software development companies was analysed to find out whether sustainable software concepts are applied. The following article presented the study of a survey at technology companies in the Region of Murcia on habits and measures for the development of sustainable software. The article was published in Applied Science in 2018 [12]. The journal is open access, Q2 and has an impact index of 2.217. Finally, an experiment was carried out to study the energy consumption of a PC. The aforementioned research extended the knowledge on energy efficiency that can be achieved with software. A catalogue of sustainable software requirements was developed. The findings were published in the Journal of Cleaner Production. The year of publication was 2021 [7]. The journal in 2019 was Q1 with an impact index of 7.246.

5.1 Paper 1

Title	Green IT and sustainable technology development: Bibliometric overview
Authors	José A. García-Berná, José L. Fernández-Alemán, Juan M. Carrillo de Gea, Joaquín Nicolás, Begoña Moros, Ambrosio Toval, Javier Mancebo, Félix García, Coral Calero
Type of publication	Journal
Source title	Sustainable Development
Year	2019
Volume	27
Number	4
Abstract	Green information technologies (GITs) constitute a field of research, whose objective is to reduce the environmental pollution caused by masses of people using and producing technology. This paper describes the search for literature related to GIT and technology sustainability in Scopus database. No restriction was imposed on the time period when carrying out the search. The data gathered revealed that the journal with the highest number of publications is Computer, and the most prolific author is Tomoya Enokido, with 45 publications. A total of 53.12% of the documents found in Scopus were Conference Paper. Although no statistically significant differences were detected, countries in the group with less CO_2 kton emissions per inhabitant and less income per capita have a higher percentage of publications. The reduction of power consumption in the cloud data centers is a hot topic for future work, because the word cloud appeared in 9 out of the 10 most frequently cited papers.
DOI	https://doi.org/10.1002/sd.1927
State	Published
Contribucions	1) Description of literature by means of bibliometric parameters 2) Statistical analysis of the important data

5.2 Paper 2

Title	Surveying the Environmental and Technical Dimensions of Sustainability in Software Development Companies
Authors	José Alberto García-Berna, Juan Manuel Carrillo de Gea, Begoña Moros, José Luis Fernández-Alemán, Joaquín Nicolás, Ambrosio Toval
Type of publication	Journal
Source title	Applied Science
Year	2018
Volume	8
Number	11
Abstract	The growing concern over the state of degradation of the environment has led to a consideration of aspects relating to sustainability in software. Bearing this in mind, we have carried out a survey of practitioners, aiming to gather information about their awareness of sustainable software, not only during the development process, but also throughout the period in which the software is used. Using the data gathered, we studied professionals' perspectives on sustainability in software development, and were able to get a picture of the current situation of the application of sustainability practices in this sector. We focused on the environmental and technical dimensions of sustainability aimed at extending the longevity of information systems and making them more energy efficient. From the results, we observed that there is a widespread desire to pursue sustainable behavior at work, even though there are not always clear guidelines on how to proceed in this endeavor.
DOI	https://doi.org/10.3390/app8112312
State	Published
Contributions	1) Knowledge from the habits and measures to produce sustainable software 2) Gaps to produce sustainable software

5.3 Paper 3

Title	Energy efficiency in software: A case study on sustainability in personal health records
Authors	José A. García-Berná, José L. Fernández-Alemán, Juan M. Carrillo de Gea, Ambrosio Toval, Javier Mancebo, Coral Calero, Félix García
Type of publication	Journal
Source title	Journal of Cleaner Production
Year	2021
Volume	282
Abstract	A personal health record is an eHealth technology in which users can observe their progress over time for a given condition. A research gap was identified in the literature concerning the study of the amount of energy that these systems need for their operation, and the energy efficiency that may be attained depending on their design. After the selection of five representative personal health records, a total of 20 tasks commonly done, and based on previous work, were performed with regard to two proposed scenarios, namely patient use and health personnel usage. The power consumption of the main components of a host machine was measured during the performance of the proposed duties. To that end, a hardware tool called the Energy Efficiency Tester was employed. The data collected were analyzed statistically, and significant differences were found in the respective consumption of the display ($\chi^2(4)$=23.782, p=0.000), the processor ($\chi^2(4)$=29.018, p=0.000) and the whole PC ($\chi^2(4)$=28.582, p=0.000). For all of

	these components, NoMoreClipBoard was the personal health record that required the least energy (57.699 W for the display, 3.162 W for the processor and 181.113 W for the whole PC). A total of two strong correlations were found in the energy consumption between the hard disk and the graphics card (r=0.791, p<0.001), and the processor and the PC (r=0.950, p<0.001). Some features generated special amounts of power consumption, such as the news wall found on PatientsLikeMe, or the use of load icons that had an impact on most PC components. In addition, an in-depth analysis of the user interfaces was performed. A discussion was carried out on the design of the user interfaces, also taking into account recommendations drawn from the literature, checking for their implementation in the personal health records selected. With the aim of promoting sustainability among software developers, a best practice guideline on sustainable software design was proposed. Basic sustainability recommendations were collected for professionals to consider when developing a software system in general, and a personal health record in particular.
DOI	https://doi.org/10.1016/j.jclepro.2020.124262
State	Published
Contributions	1) Power consumption measurements 2) Software sustainability recommendations catalogue

6 Conclusions

Building quality and sustainable software is essential for the industry to move forward, offering environmentally friendly products. In this work, the problem of energy efficiency in ISs was addressed from the software perspective. This field of study is not widely known by technicians and should be enriched with validated artifacts. It is worth noting that sustainability aspects in software are complicated to address. They can be manageable when using a particular technology. Thus, technologies play an important role in software projects to build energy efficient system.

Environmental awareness from a technological perspective should be promoted not only in the academic area but also in everyday life. The results of the thesis point to the fact that energy efficiency and renewable energies are going to be one of the most relevant topics of the current century. The industry has to focus on offering quality products. By way of example, a product that is energy efficient is a quality product that brings great value to the customer. In fact, if a product is energy efficient, it stands out in the market to be purchased. On the other hand, the use of renewable energies is a reality that must be encouraged in today's globalised world. Governments must create policies that make common the use of renewable energies.

The research presented in this manuscript fulfilled the proposed goals. Firstly, the literature was studied from a bibliometric perspective. As a result, it was observed the relevance that energy efficiency is gaining in ISs over the last years. This is an important fact given the deterioration of the environment. In addition, there was a clear upward trend in the number of publications related to the aforementioned topic. It is also remarkable that more literature on energy efficiency in ICTs was published in countries with lower gross domestic product and lower greenhouse gas emissions per inhabitant. It therefore appears that in developing countries, which also pollute less, research on sustainable technologies is an important topic [11].

On the other hand, the survey conducted in software development companies brought data on sustainable software production. The results of the survey showed a general lack of knowledge on how to reduce energy consumption through software. Moreover, in most cases software professionals do not address the aforementioned problem. There was a willingness to acquire knowledge on these issues despite the difficulties found. For this reason, it is important to make it easier for technicians to attain sustainable software [12].

The main contribution of the research was achieved in the third publication of the compendium. The energy consumption of the main components of a computer was analysed. Energy measurements were collected during the performance of some representative tasks in a set of PHRs used as a case study. As a result of this experiment, a catalogue of recommendations (CAT-SUST) for creating energy-efficient software was proposed. An artifact like CAT-SUST is relevant in the area of Software Engineering, providing recommendations to have a more accurate idea on sustainable software production. The recommendations on sustainable software introduced in this dissertation can be applied to all types of ISs, thus extending the potential energy savings that can be achieved.

CAT-SUST was validated during the course of the PhD. The construction of CAT-SUST was based on software quality. PHRs were used as a case study. Recommendations for energy efficiency were validated from the study of the characteristics of GUIs in the aforementioned systems. This work was further extended by looking for correlations between usability and energy consumption. The results of these studies confirmed the research hypothesis: a system in which sustainability aspects of software were considered is at the same time more energy efficient [7, 15].

Building high quality systems does not have zero impact on energy consumption. As future work we intend to study how software quality impacts on the energy consumption of a hardware system. In order to better define the scope of the study, software quality components will be dealt with in isolation. As an example, GUI components will be studied from the point of view of usability and energy consumption. The aim will be to assess whether high usability measures are correlated with reduced energy consumption. The catalogue of recommendations will be extended with new requirements derived from the research.

Labelling is the process of classifying an artifact, and can help spread awareness of the energy efficiency of software. Providing this information allows users to know at a glance that software is energy-aware. It is necessary to define software sustainability guidelines to streamline software audits, and categorize software depending on power consumption. Currently this activity is rarely performed. As stated before, it can be complicated due to the inherent variability of the technology. Further experiments will be conducted in the future to prove that by knowing the hardware technology in advance, reductions in energy consumption can be achieved through software. This scenario can be established by means of a conditioned compilation, detecting the hardware. A native compilation will be performed to consider energy efficiency. Depending on the hardware, specific code could be used for compilation. This insight could be employed in mobile applications. Its high replication could bring important power consumption reductions.

An IDE that is aware of energy consumption aspects could be developed. Such an artifact would alert the professionals to code software alternatives depending on the hardware. Furthermore, by knowing the structure of the code itself, artificial intelligence functionality could be added in order to propose improvements so that the code needs as little energy as possible depending on the hardware. Along these lines, a software energy efficiency calculator could be developed, which would provide a real-time energy efficiency score for the software under test.

During the doctorate work, a social experiment was carried out in order to promote the efficient use of energy on PCs in the computer rooms of the University of Murcia. The experiment consisted of displaying banners on screens and stickers near the computer with messages about leaving the computer in standby mode instead of on. At the beginning of the exam sessions, students were asked to avoid leaving the computer on at the end of the exam. This experiment was carried out in several faculties of the university. As a result, the students of the Computer Science degree switched off all computers, without the need for banners. On the other hand, the other faculties did not know the difference between suspending and hibernating the computer. In addition, there was a banner blindness effect with no significant change in the behaviour of the users. In the future, we intend to work in collaboration with psychology professors to extract the reasons why students with a technological profile studies are more aware of the importance of turning off computers when they finish using them.

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REGIONAL & URBAN PLANNING -- SSCI
GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY -- SSCI

LANGUAGES
English

PUBLICATION FREQUENCY
6 issues/year

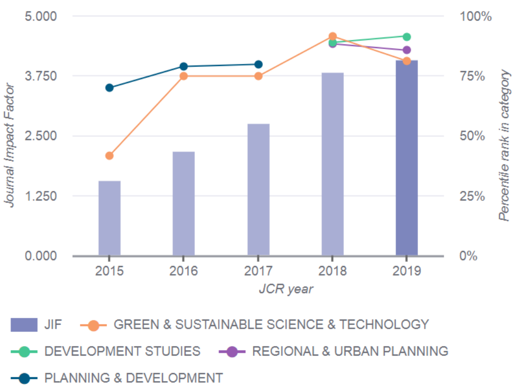
Current Year | 2018 | 2017 | All Years

The data in the two graphs below and in the Journal Impact Factor calculation panels represent citation activity in 2019 to items published in the journal in the prior two years. They detail the components of the Journal Impact Factor. Use the "All Years" tab to access key metrics and additional data for the current year and all prior years for this journal.

Journal Impact Factor Trend 2019

Printable Version

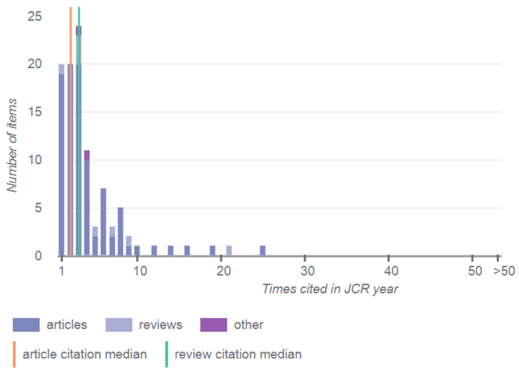
4.082
2019 Journal Impact Factor



Citation distribution 2019

Printable Version

2 Article citation median
3 Review citation median



Source data | Box plot | Rank | Cited Journal Data | Citing Journal Data | Journal Relationships

Rank

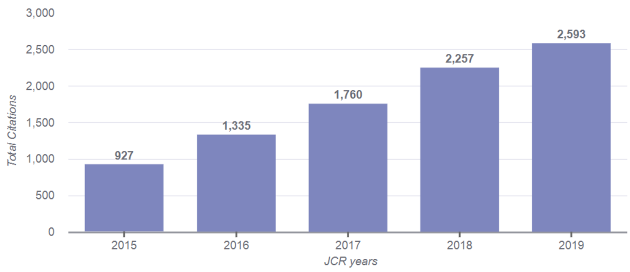
JCR Impact Factor

JCR Year	DEVELOPMENT STUDIES			GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY			REGIONAL & URBAN PLANNING			PLANNING & DEVELOPMENT		
	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile
2019	4/41	Q1	91.463	2/8	Q1	81.250	6/39	Q1	85.897	n/a	n/a	n/a
2018	5/41	Q1	89.024	1/6	Q1	91.667	5/39	Q1	88.462	n/a	n/a	n/a
2017	n/a	n/a	n/a	2/6	Q2	75.000	n/a	n/a	n/a	12/57	Q1	79.825
2016	n/a	n/a	n/a	2/6	Q2	75.000	n/a	n/a	n/a	12/55	Q1	79.091
2015	n/a	n/a	n/a	4/6	Q3	41.667	n/a	n/a	n/a	17/55	Q2	70.000

ESI Total Citations

Rank

JCR Year	SOCIAL SCIENCES, GENERAL
2019	443/2310-Q1
2018	480/2234-Q1
2017	542/2184-Q1
2016	570/2145-Q2
2015	666/2132-Q2
2014	613/2084-Q2
2013	653/2036-Q2



Key Indicators 2019

IMPACT METRICS

Total Cites	2,593	✓Trend
Journal Impact Factor	4.082	Trend
5 Year Impact Factor	4.341	Trend
Immediacy Index	1.024	Trend
Impact Factor without Journal Self Cites	3.033	Trend

INFLUENCE METRICS

Eigenfactor Score	0.00159	Trend
Article Influence Score	0.565	Trend
Normalized Eigenfactor	0.19435	Trend

SOURCE METRICS

Citable Items	84	Trend
% Articles in Citable Items	90.48	Trend
Average JIF Percentile	86.204	Trend
Cited Half-Life	8.0	Trend
Citing Half-Life	7.8	Trend

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InCites Journal Citation Reports

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Applied Sciences-Basel

ISSN: ****-****
eISSN: 2076-3417
MDPI
ST ALBAN-ANLAGE 66, CH-4052 BASEL, SWITZERLAND
SWITZERLAND

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TITLES
ISO: Appl. Sci.-Basel
JCR Abbrev: APPL SCI-BASEL

CATEGORIES
ENGINEERING, MULTIDISCIPLINARY -- SCIE
PHYSICS, APPLIED -- SCIE
MATERIALS SCIENCE, MULTIDISCIPLINARY -- SCIE
CHEMISTRY, MULTIDISCIPLINARY -- SCIE

LANGUAGES
English

PUBLICATION FREQUENCY
24 issues/year

Open Access from 2011

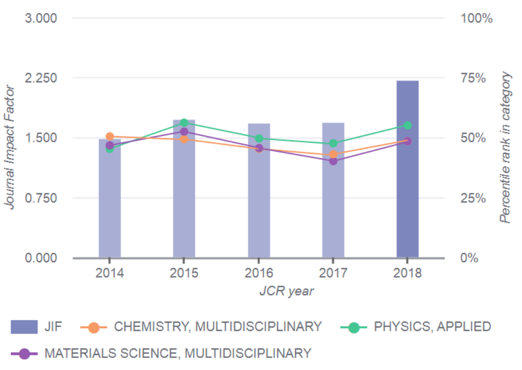
Current Year | 2018 | 2017 | All Years

The data in the two graphs below and in the Journal Impact Factor calculation panels represent citation activity in 2018 to items published in the journal in the prior two years. They detail the components of the Journal Impact Factor. Use the "All Years" tab to access key metrics and additional data for the current year and all prior years for this journal.

Journal Impact Factor Trend 2018

Printable Version

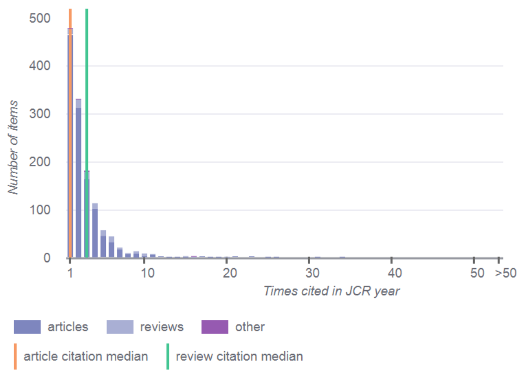
2.217
2018 Journal Impact Factor



Citation distribution 2018

Printable Version

1 Article citation median
3 Review citation median



Source data | Box plot | Rank | Cited Journal Data | Citing Journal Data | Journal Relationships

Rank

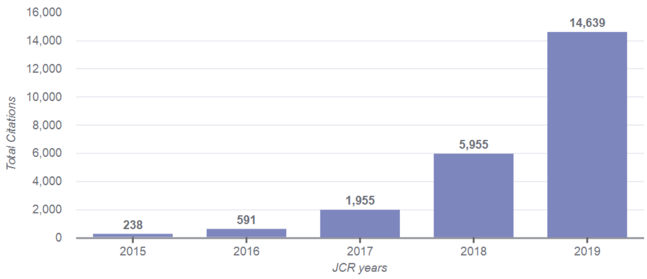
JCR Impact Factor

JCR Year	CHEMISTRY, MULTIDISCIPLINARY			ENGINEERING, MULTIDISCIPLINARY			MATERIALS SCIENCE, MULTIDISCIPLINARY			PHYSICS, APPLIED		
	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile
2019	88/177	Q2	50.565	32/91	Q2	65.385	161/314	Q3	48.885	63/155	Q2	59.677
2018	89/172	Q3	48.547	n/a	n/a	n/a	151/293	Q3	48.635	67/148	Q2	55.068
2017	98/171	Q3	42.982	n/a	n/a	n/a	171/285	Q3	40.175	77/146	Q3	47.603
2016	91/166	Q3	45.482	n/a	n/a	n/a	150/275	Q3	45.636	75/148	Q3	49.662
2015	83/163	Q3	49.387	n/a	n/a	n/a	129/271	Q2	52.583	64/145	Q2	56.207

ESI Total Citations

Rank

JCR Year	ENGINEERING
2019	82/909-Q1
2018	211/893-Q1
2017	367/867-Q2
2016	579/861-Q3
2015	695/850-Q4



Key Indicators 2018

IMPACT METRICS

Total Cites	5,955	✓Trend
Journal Impact Factor	2.217	Trend
5 Year Impact Factor	2.287	Trend
Immediacy Index	0.507	Trend
Impact Factor without Journal Self Cites	1.731	Trend

INFLUENCE METRICS

Eigenfactor Score	0.00889	Trend
Article Influence Score	0.346	Trend
Normalized Eigenfactor	1.05757	Trend

SOURCE METRICS

Citable Items	2,672	Trend
% Articles in Citable Items	93.30	Trend
Average JIF Percentile	50.750	Trend
Cited Half-Life	1.6	Trend
Citing Half-Life	6.5	Trend

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JOURNAL OF CLEANER PRODUCTION

ISSN: 0959-6526
eISSN: 1879-1786
ELSEVIER SCI LTD
THE BOULEVARD, LANGFORD LANE, KIDLINGTON, OXFORD OX5 1GB, OXON, ENGLAND
USA

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TITLES
ISO: J. Clean Prod.
JCR Abbrev: J CLEAN PROD

CATEGORIES
GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY -- SCIE
ENGINEERING, ENVIRONMENTAL -- SCIE
ENVIRONMENTAL SCIENCES -- SCIE

LANGUAGES
English

PUBLICATION FREQUENCY
30 issues/year

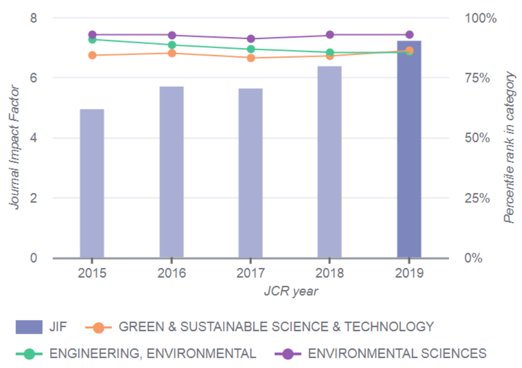
Current Year | 2018 | 2017 | All Years

The data in the two graphs below and in the Journal Impact Factor calculation panels represent citation activity in 2019 to items published in the journal in the prior two years. They detail the components of the Journal Impact Factor. Use the "All Years" tab to access key metrics and additional data for the current year and all prior years for this journal.

Journal Impact Factor Trend 2019

Printable Version

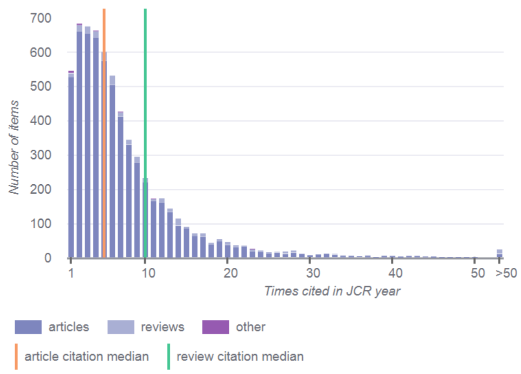
7.246
2019 Journal Impact Factor



Citation distribution 2019

Printable Version

5 Article citation median
9.5 Review citation median



Source data | Box plot | Rank | Cited Journal Data | Citing Journal Data | Journal Relationships

Rank

JCR Impact Factor

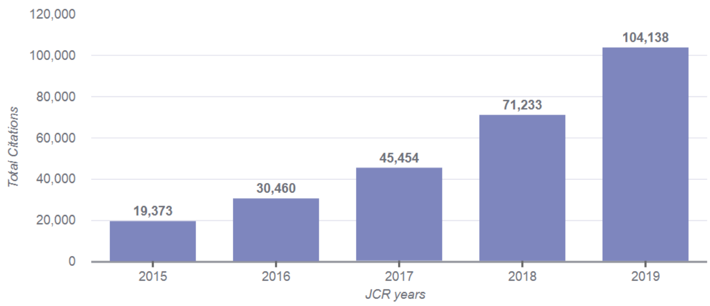
JCR Year	GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY			ENGINEERING, ENVIRONMENTAL			ENVIRONMENTAL SCIENCES		
	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile
2019	6/41	Q1	86.585	8/53	Q1	85.849	19/265	Q1	93.019
2018	6/35	Q1	84.286	8/52	Q1	85.577	18/251	Q1	93.028
2017	6/33	Q1	83.333	7/50	Q1	87.000	21/242	Q1	91.529
2016	5/31	Q1	85.484	6/49	Q1	88.776	17/229	Q1	92.795
2015	5/29	Q1	84.483	5/50	Q1	91.000	16/225	Q1	93.111

ESI Total Citations

Rank

JCR Year	ENGINEERING
2019	4/909-Q1
2018	6/893-Q1
2017	14/867-Q1
2016	24/861-Q1
2015	29/850-Q1
2014	47/838-Q1
2013	62/837-Q1

View All Years



Key Indicators 2019

IMPACT METRICS		
Total Cites	104,138	✓Trend
Journal Impact Factor	7.246	Trend
5 Year Impact Factor	7.491	Trend
Immediacy Index	1.904	Trend
Impact Factor without Journal Self Cites	5.520	Trend

INFLUENCE METRICS		
Eigenfactor Score	0.12910	Trend
Article Influence Score	0.969	Trend
Normalized Eigenfactor	15.73345	Trend

SOURCE METRICS		
Citable Items	4,059	Trend
% Articles in Citable Items	93.50	Trend
Average JIF Percentile	88.484	Trend
Cited Half-Life	2.9	Trend
Citing Half-Life	5.8	Trend

PAPERS IN JCR JOURNALS NOT CONSIDERED IN THE THESIS BY COMPENDIUM

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InCites Journal Citation Reports — Clarivate™

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International Journal of Environmental Research and Public Health

ISSN: 1661-7827
eISSN: 1660-4601
MDPI
ST ALBAN-ANLAGE 66, CH-4052 BASEL, SWITZERLAND
SWITZERLAND

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TITLES
ISO: Int. J. Environ. Res. Public Health
JCR Abbrev: INT J ENV RES PUB HE

CATEGORIES
PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH -- SCIE
ENVIRONMENTAL SCIENCES -- SCIE

LANGUAGES
English

PUBLICATION FREQUENCY
24 issues/year

Open Access from 2004

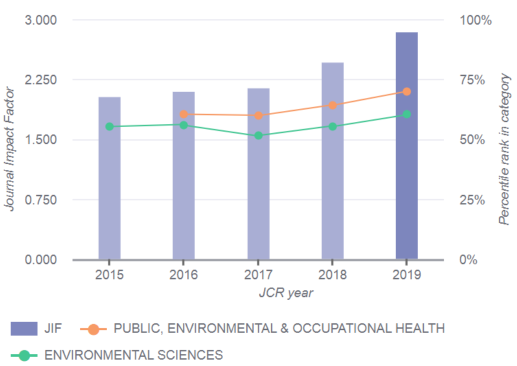
Current Year 2018 2017 All Years

The data in the two graphs below and in the Journal Impact Factor calculation panels represent citation activity in 2019 to items published in the journal in the prior two years. They detail the components of the Journal Impact Factor. Use the "All Years" tab to access key metrics and additional data for the current year and all prior years for this journal.

Journal Impact Factor Trend 2019

Printable Version

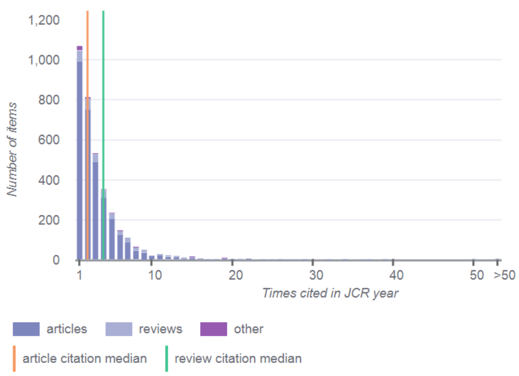
2.849
2019 Journal Impact Factor



Citation distribution 2019

Printable Version

2 Article citation median **4** Review citation median



Source data | Box plot | Rank | Cited Journal Data | Citing Journal Data | Journal Relationships

Rank

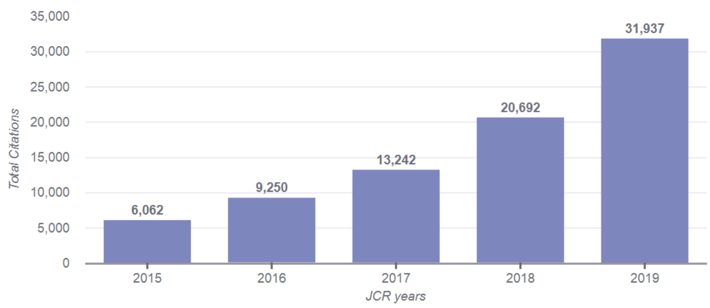
JCR Impact Factor

JCR Year	ENVIRONMENTAL SCIENCES			PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH		
	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile
2019	105/265	Q2	60.566	58/193	Q2	70.207
2018	112/251	Q2	55.578	67/186	Q2	64.247
2017	117/242	Q2	51.860	73/181	Q2	59.945
2016	101/229	Q2	56.114	70/176	Q2	60.511
2015	101/225	Q2	55.333	n/a	n/a	n/a

ESI Total Citations

Rank

JCR Year	ENVIRONMENT/ECOLOGY
2019	22/380-Q1
2018	33/370-Q1
2017	48/361-Q1
2016	55/341-Q1
2015	71/338-Q1
2014	82/324-Q1
2013	100/312-Q2



Key Indicators 2019

IMPACT METRICS		
Total Cites	31,937	✓Trend
Journal Impact Factor	2.849	Trend
5 Year Impact Factor	3.127	Trend
Immediacy Index	0.499	Trend
Impact Factor without Journal Self Cites	2.341	Trend

INFLUENCE METRICS		
Eigenfactor Score	0.06156	Trend
Article Influence Score	0.659	Trend
Normalized Eigenfactor	7.50261	Trend

SOURCE METRICS		
Citable Items	5,093	Trend
% Articles in Citable Items	92.28	Trend
Average JIF Percentile	70.784	Trend
Cited Half-Life	3.2	Trend
Citing Half-Life	7.2	Trend

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JOURNAL OF MEDICAL SYSTEMS

ISSN: 0148-5598
eISSN: 1573-689X
SPRINGER
ONE NEW YORK PLAZA, SUITE 4600 , NEW YORK, NY 10004, UNITED STATES
USA

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TITLES
ISO: J. Med. Syst.
JCR Abbrev: J MED SYST

CATEGORIES
HEALTH CARE SCIENCES & SERVICES -- SCIE
MEDICAL INFORMATICS -- SCIE

LANGUAGES
English

PUBLICATION FREQUENCY
12 issues/year

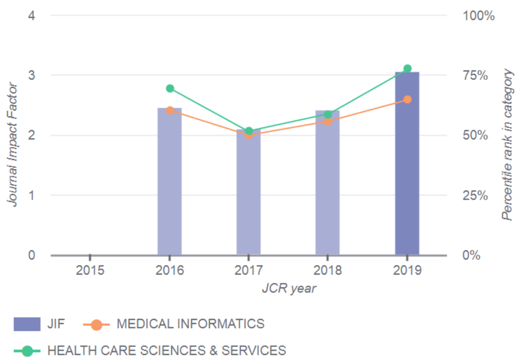
Current Year | 2018 | 2017 | All Years

The data in the two graphs below and in the Journal Impact Factor calculation panels represent citation activity in 2019 to items published in the journal in the prior two years. They detail the components of the Journal Impact Factor. Use the "All Years" tab to access key metrics and additional data for the current year and all prior years for this journal.

Journal Impact Factor Trend 2019

Printable Version

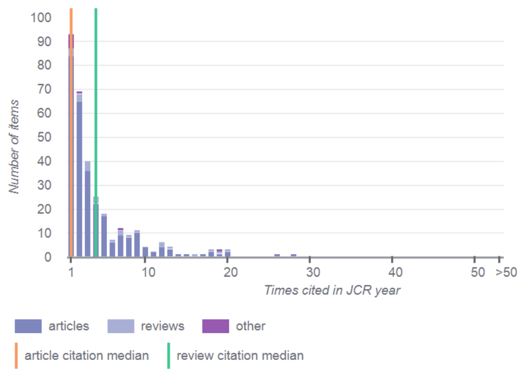
3.058
2019 Journal Impact Factor



Citation distribution 2019

Printable Version

1 Article citation median
4 Review citation median



Source data Box plot Rank Cited Journal Data Citing Journal Data Journal Relationships

Rank

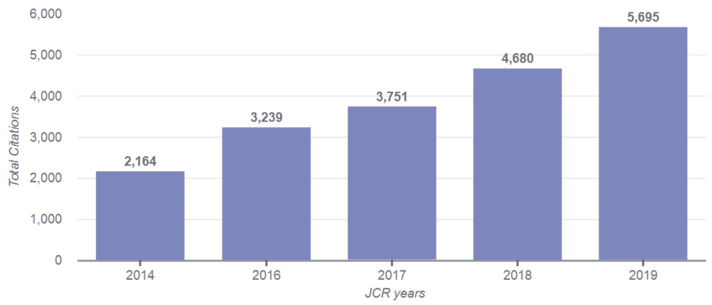
JCR Impact Factor

JCR Year	HEALTH CARE SCIENCES & SERVICES			MEDICAL INFORMATICS		
	Rank	Quartile	JIF Percentile	Rank	Quartile	JIF Percentile
2019	23/102	Q1	77.941	10/27	Q2	64.815
2018	41/98	Q2	58.673	12/26	Q2	55.769
2017	46/94	Q2	51.596	13/25	Q3	50.000
2016	28/90	Q2	69.444	10/24	Q2	60.417
2015	n/a	n/a	n/a	n/a	n/a	n/a

ESI Total Citations

Rank

JCR Year	CLINICAL MEDICINE
2019	524/2180-Q1
2018	575/2108-Q2
2017	643/2061-Q2
2016	650/2029-Q2
2015	
2014	744/1975-Q2
2013	892/1955-Q2



Key Indicators 2019

IMPACT METRICS		
Total Cites	5,695	✓Trend
Journal Impact Factor	3.058	Trend
5 Year Impact Factor	3.072	Trend
Immediacy Index	0.840	Trend
Impact Factor without Journal Self Cites	2.646	Trend

INFLUENCE METRICS		
Eigenfactor Score	0.00703	Trend
Article Influence Score	0.523	Trend
Normalized Eigenfactor	0.85676	Trend

SOURCE METRICS		
Citable Items	338	Trend
% Articles in Citable Items	96.45	Trend
Average JIF Percentile	71.378	Trend
Cited Half-Life	4.6	Trend
Citing Half-Life	5.3	Trend

Papers accepted as a PhD candidate

JOURNAL PAPERS

- **García-Berná, José Alberto**, Ouhbi, Sofia, Fernández-Alemán, José Luis, Carrillo de Gea, Juan Manuel, Nicolás, Joaquín (2021). Investigating the impact of usability on energy efficiency of web-based personal health records. *Journal of Medical Systems*, 45(6), 1-13. Índice de impacto 3,058 y Q1 en 2019.

- **García Berná, José Alberto**, Ouhbi, Sofia, Fernández Alemán, José Luis, Carrillo de Gea, Juan Manuel, Nicolás, Joaquín, Moros, Begoña & Toval, Ambrosio (2021). A study on the relationship between usability of GUIs and power consumption of a PC: The case of PHRs. *International Journal of Environmental Research and Public Health*, 18(4), 1-23. Índice de impacto 2,849 y Q2 en 2019.

- **García Berná, José Alberto**, Fernández Alemán, José Luis, Carrillo de Gea, Juan Manuel, Toval, Ambrosio, Mancebo, Javier, Calero, Coral & García, Félix (2021). Energy efficiency in software: A case study on sustainability in personal health records. *Journal of Cleaner Production*, 282, 124262. Índice de impacto 7,246 y Q1 en 2019.

- **García Berná, José Alberto**, Ouhbi, Sofia, Benmouna, Brahim, García Mateos, Ginés, Fernández Alemán, José Luis, Molina Martínez, José Miguel (2020). Systematic mapping study on remote sensing in agriculture. *Applied Science*, 10(10), 1-29. Índice de impacto 2,474 y Q2 2019.

- Calero, Coral, Mancebo, Javier, García, Félix, Moraga, María Ángeles, **García Berná, José Alberto**, Fernández Alemán, José Luis, Toval, Ambrosio (2019). 5Ws of green and sustainable software. *Tsinghua Science and Technology*, 25(3), 401-414. Índice de impacto 1,328 y Q3 2019.

- Mayordomo Martínez, Diego, Sánchez Aarnoutse, J., Carrillo de Gea, Juan Manuel, **García Berná, José Alberto**, Fernández Alemán, José Luis, García Mateos, Ginés. (2019). Design and development of a mobile app for accessible beach tourism information for people with disabilities. *International Journal of Environmental Research and Public Health*, 16(12), 1-16. Índice de impacto 2,849 y Q2 en 2019.

- **García Berná, José Alberto**, Fernández Alemán, José Luis, Carrillo de Gea, Juan Manuel, Nicolás, Joaquín, Moros, Begoña, Toval, Ambrosio, Mancebo, Javier, García, Félix & Calero, Coral (2019). Green IT and sustainable technology development: Bibliometric overview. *Sustainable Development*, 27(4), 613-636. Índice de impacto 4,082 y Q1 en 2019.

- Mayordomo Martínez, Diego, Carrillo de Gea, Juan Manuel,García Mateos, Ginés, **García Berná, José Alberto**, Fernández Alemán, José Luis, Rosero López, Saúl, Parada Sarabia & Salvador, García Hernández, Manuel (2019). Sustainable accessibility: A mobile app for helping people with disabilities to search accessible shops. *International Journal of Environmental Research and Public Health*, 16(4), 1-18. Índice de impacto 2,849 y Q2 en 2019.

- **García Berná, José Alberto**, Carrillo de Gea, Juan Manuel, Moros, Begoña, Fernández Alemán, José Luis, Nicolás, Joaquín & Toval, Ambrosio (2018). Surveying the environmental and technical dimensions of sustainability in software development companies. *Applied Sciences*, 8(11), 1-16. Índice de impacto 2,217 y Q2 en 2018.

CONFERENCE PAPERS

- **García Berná José Alberto**, Ouhbi, Sofia, Fernández Alemán, José Luis, Carrillo de Gea, Juan Manuel & Nicolás Ros, Joaquín (2020). Energy efficiency and usability of web-based personal health records. WorldCIST'20: 8th World Conference on Information Systems and Technologies, Budva, Montenegro. Rank C en CORE2020.

- Drissi, Nidal, Ouhbi, Sofia, **García Berná, José Alberto**, Idrissi, Mohammed Abdou Janati & Ghogho, Mounir (2020). Sensor-based solutions for mental health care: A systematic literature review. HealthINF'20: 13th International conference on health informatics, Valletta, Malta. Rank C en CORE2020.

- García Sánchez, Francisco, **García Berná, José Alberto**, Fernández Alemán, José Luís & Toval, Ambrosio (2019). Aplicación de juegos serios en la enseñanza de Ingeniería de Requisitos y Gestión de Proyectos. JENUI'19: XXV Edición de las Jornadas sobre la Enseñanza Universitaria de la Informática, Murcia, Spain.

- Mayordomo Martínez, Diego, Sánchez Aarnoutse, Juan Carlos, Merzoukid, Khalil, García Hernández, Manuel, Carrillo de Gea, Juan Manuel, **García Berná, José Alberto**, Fernández Alemán, José Luis, Idri, Ali & García Mateos, Ginés (2019). Improving accessibility for people with disabilities: A case study on inclusive beach tourism. EMBC'19: 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Berlin, Germany. Rank C en CORE2018.

- Hosni, Mohamed, Carrillo de Gea, Juan Manuel, Idri, Ali, Fernández Alemán, José Luis & **García Berná, José Alberto** (2019). Using ensemble classification methods in lung cancer disease. EMBC'19: 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Berlin, Germany. Rank C en CORE2018.

- **García Berná, José Alberto**, Fernandez-Aleman, José Luis, Carrillo de Gea, Juan Manuel, Nicolás, Joaquín, Moros, Begoña, Toval, Ambrosio, Mancebo, Javier, Calero, Coral & García, Félix (2019). Estudio de La sostenibilidad energética en los portales de carpeta personal de salud. JISBD'19: XXIV Jornadas de Ingeniería del Software y Bases de Datos, Cáceres, Spain.

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