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The role of digitalisation in enhancing automatic control and renewable energy management in Algeria: An empirical study at the Centre for the Development of Renewable Energies (CDER), Bouzaréah

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Abstract---This study aims to examine the role of digitalisation in enhancing automatic control and the management of renewable energies in Algeria, with a particular focus on practical implementation within the Centre for the Development of Renewable Energies (CDERs) in Bouzaréah. The study adopts two complementary approaches: a theoretical approach to derive the fundamental concepts of digitalisation and renewable energy and an empirical approach based on direct observation, analysis of technical documents, and interviews with engineers and researchers in the Department of Solar Thermal Systems. The findings indicate that the Centre has made evident progress in the digitalisation process through the digitisation of experimental and thermal data and their integration with sensing systems. This has contributed to improved precision in automatic control and to the optimal utilisation of renewable energies.

Keywords---digitalisation, renewable energies, Centre for the Development of Renewable Energies (CDER), Bouzaréah.
JEL classification: O33; Q42

Introduction

Digitalisation has garnered broad interest among researchers and organisations, as it represents the third generation of technological development, combining the technologies of the first and second generations and advancing them towards a more integrated, intelligent level. The first generation

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witnessed, in the 1960s and 1970s, the emergence of computerised information systems that enabled administrators and analysts to record and process data with accuracy and efficiency. With the subsequent development of technological infrastructure, the second generation emerged in the late twentieth century, when integrated systems such as Enterprise Resource Planning (ERP) appeared, providing more comprehensive tools and allowing accountants and administrators to access information with ease and high reliability.

The third generation, namely, the era of digitalisation, represents an advanced phase that brings together intelligence, connectivity, and data integration, thereby reconfiguring the core of organisational processes. It gradually permeated all sectors and then accelerated with the development of computing and the expansion of digital systems within institutions before being significantly reinforced in the new millennium with the emergence of big data. Binary encoding (0 and 1), the fundamental language of the computer, has come to permeate diverse aspects of life, from children's games to major institutions and even the governments of states that are moving towards advanced levels of digital transformation.

Digitalisation has brought about a profound shift in economic and social patterns to the extent that it is rare to find an individual who does not have a direct or indirect relationship with digital technologies. Conversely, the term digital illiteracy has emerged to describe those who lack the skills to engage with modern technology.

Today, digitalisation stands out as one of the fundamental pillars of economic development, particularly as the world transitions towards sustainable growth strategies. In the renewable energy sector, digitalisation has become a pivotal element in improving the efficiency of solar and wind energy production, managing smart grids, monitoring performance, and optimising consumption. This renders the integration of digital technology a necessary condition for enhancing the effectiveness and sustainability of renewable energies and supporting the competitiveness of institutions and states alike.
This study aims to shed light on the topic of digitalisation and its role in developing and improving renewable energy systems by applying the subject to the Centre for the Development of Renewable Energies (CDER) in Bouzaréah, Algiers, and attempting to address the most prominent theoretical contributions in this field.

Accordingly, this study will attempt to answer the following problematic question: To what extent does digitalisation contribute to the development of automatic control systems for renewable energies within the Centre for the Development of Renewable Energies in Bouzaréah, and what are the limits and effectiveness of its deployment in protecting and improving the performance of the Centre's solar and wind energy systems?

❖ The theoretical framework of the study

In this part of the study, we analyse the theoretical and intellectual frameworks of digitalisation and renewable energies, focusing on the most salient issues addressed in the literature in this context.

First: Digitalisation

Definition of digitalisation:

The term digitalisation has undergone notable development, with the proliferation of related concepts such as digitisation, digitalisation, and digital transformation. A clear distinction between these terms emerges in some fields, although ambiguity persists in others. Digitisation refers to the purely technical process of converting analogue data, such as documents, images, and audio signals, into digital data composed of bits and bytes, enabling their computational processing (Ilham, 2022, p. 1).

In contrast, digitalisation refers to the use of digital technologies to improve business processes within organisations. In contrast, digital transformation goes beyond all of this to entail a radical change in

business models and strategies, in a manner that is consistent with the organisation's objectives and that provides new opportunities for growth and productivity (Sultan, 2025, p. 1).

Terry Kuny (1997) views digitisation as the process of converting information resources in their various forms into a format readable by computer technologies through a binary system (bits), which is considered the basic unit of information for an information system based on computer technologies.
Munir Hamza (2011) defines digitisation as the conversion of data into a digital form for processing by a computer; it usually refers to the conversion of printed texts or images into binary signals. This means dispensing with paper-based transactions and replacing them with electronic office operations through extensive use of information technology (Mohammed, 2011, p. 120).

Fatima and Farida (2022) define digitalisation as "the process through which information is transformed from its current traditional form into a digital form, whether this information consists of images, textual data, an optical file, or any other form. It can also be clarified as a process of digital replication that enables the conversion of any document, regardless of its type, into a digital sequence" (Rabhi & Zenini, 2022, p. 162).

Drawing on all the preceding definitions, we can propose the following operational definition of digitalisation, which refers to the totality of technical processes through which various types of data, documents, images, and signals are transformed from their analogue or traditional form into binary digital formats (Bits & Bytes) that are amenable to processing, storage, and retrieval by computer systems to improve data accuracy, facilitate their circulation, and ensure the possibility of their use within the digital systems and embedded software of the organisation.

The importance of digitalisation:
Digital transformation offers numerous benefits across institutions, companies, and even governments, aiming to improve performance and deliver high-quality, efficient services. The importance of digitalisation can be presented in the following points:

- Enhancing work within a single system and avoiding duplication of work (Hanan, 2024, p. 63).
- Discovering new methods and means of production through technological development leads to increased production and improved quality (Khalaf, 2007, p. 147).
- Reducing cost, time, and effort for all parties concerned with electronic transactions while providing expenditures that were incurred under traditional operations (Bou Taleb & Sanousi, 2025, p. 244).
- Digitalisation contributes to economic growth, creates new job opportunities, and encourages innovation (Ammara & Ben Salhiya, 2023, p. 48).
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The characteristics of digitalisation:
The pressing need for digitalisation and the radical changes it has brought about have endowed it with essential characteristics, particularly given its capacity to seek effective ways to obtain information and knowledge with great accuracy and speed by relying on digital technology, the internet, and the Internet of Things (IoT), among others, to enhance opportunities for interaction and communication among employees automatically within a virtual digital environment. In contrast to traditional organisations, it possesses a distinctive characteristic that, at its essence, seeks to keep its information, knowledge, and work completely confidential. Accordingly, the characteristics of digitalisation can be summarised as follows: paperless management, placeless management, timeless management, management without new organisational structures, speed and clarity, nonrestriction by time and place, information management and retention, flexibility, increased proficiency, simplification of procedures, and cost reduction (Roufia, 2025, p. 134).

Requirements for Digitalisation

To implement a digitalisation project, an integrated infrastructure must be available, encompassing the following needs and requirements:

- Financial requirements: Financial resources are a decisive element for the success of any project, particularly in the field of digital transformation. These resources are determined by the project's needs and specified objectives.
- Material requirements: These requirements include all the physical devices and equipment necessary to support the digital input and output process, such as computers, scanners, digital imaging devices, and optical character recognition technologies.
- Human requirements: The human element, across different levels of competence and expertise, represents an essential condition for the implementation and management of any digital project.
- Legislative requirements: These include legal frameworks that ensure data protection and privacy in digital projects, such as intellectual property rights laws and related legislation (Hasnawi & Qahairiya, 2025, p. 30).

Second: Renewable energy

Investment in renewable energy is considered one of the most important contemporary topics in global energy economics. Achieving economic and social development is an aspiration and a goal for every state, and this goal is realised only through the availability of energy services. This is particularly so given that prevailing development patterns have led, on the one hand, to a significant depletion of conventional energy sources and, on the other hand, to severe environmental pollution, the intensity of which has increased over recent decades. This has sounded the alarm in light of evident climate change and the search for secure energy supplies worldwide.

Accordingly, efforts have begun in research and development in renewable energy through substantial financial investment. Energy strategies have been placed among primary priorities, alongside programmes aimed at the optimal exploitation of these resources to meet local energy consumption needs at the lowest possible cost (Touat & Zerrouki, 2022, p. 62).

In recent years, Algeria, like many countries worldwide, has witnessed growing interest in investing in renewable energy, recognising the importance of the energy transition and reducing dependence on traditional fossil fuels. The state has adopted several strategies and national programs aimed at developing and diversifying clean energy sources, particularly in light of the significant natural potential it possesses, especially high solar irradiation and vast areas suitable for installing energy systems.

Solar energy constitutes the backbone of renewable energy projects in Algeria, followed by wind energy, which is beginning to gain a growing presence through pilot projects in certain provinces, in addition to its untapped potential in other areas such as geothermal and bioenergy. This national orientation stands out as part of a comprehensive vision aimed at strengthening energy independence, reducing carbon emissions, and achieving sustainable development on the basis of clean, renewable energy (Farida, 2015, p. 13).

Concept of Renewable Energies

Definition of Energy:

Energy has been defined in previous texts and studies in several synonymous ways, with the premise that it is "the ability to perform work." It is a concept that describes the capacity to bring about change or a tangible effect, whether through lifting weights, operating machines, or even vital processes within living organisms. These definitions highlight that energy is neither destroyed nor created from nothing; instead, it is transformed from one form to another. Its sources are also diverse, ranging from the potential energy of waterfalls to the energy used in economic and productive processes.

At a deeper theoretical level, Einstein presented his revolutionary view of energy through his theory of relativity, expressed by the most famous equation in physics, $E = mc^2$. This equation states that energy (E) equals the product of mass (m) and the square of the speed of light in a vacuum (c^2). The importance of this equation lies in its ability to convert matter into enormous amounts of energy, which scientifically opened the door to the atomic and nuclear energy era, where vast quantities of energy are released through transformations in the atomic nucleus (Al-Din, 2018, p. 32).

Definition of Renewable Energies

Mokhtaria and Fatima Zahra (2018) define renewable energy as energy derived from natural resources that are replenished and cannot be depleted, as they represent natural sources of energy that do not run out and can be easily converted into alternative forms (Din & Zerrouat, 2018, p. 74).

Aidi and Moumen (2019) define renewable energy as a primary source found in nature and continually available. They include hydropower, solar, wind, geothermal, and biomass energy, as well as tidal and ocean energy (Aidi & Moumen, 2019, p. 73).

Ben Lakhdar and Youssef (2020) also define renewable energy as any energy generated from inexhaustible natural resources that are replenished faster than they are used. The possibility of exploitation and conversion into primary energy sources, such as fuel and electricity, further characterises their sources.

Younsi Ahlam (2023) considers renewable energies to be resources obtained from energy sources that recur naturally in an automatic and periodic manner (Younsi, 2023, p. 30).

On the basis of the range of definitions proposed above, renewable energies are natural resources that are naturally replenished and are not depleted by human use and can be easily converted into electrical or thermal energy to power various systems.

According to this definition, renewable energies are understood not only as inexhaustible natural sources but also as systems amenable to technical processing, measurement, and development, thereby enabling the study of ways to improve their performance through digitalisation and automatic control.

Sources of Renewable Energy:

Renewable energy comprises diverse sources, making it an optimal solution to avoid the problems of energy scarcity and depletion. Among the most important sources of renewable energy are the following:

- **Solar energy**: The sun is one of the most significant sources of light and heat on Earth. This energy is distributed across the Earth according to its proximity to the equator, with the equator receiving the most significant share. The thermal energy generated by solar radiation is utilised by converting it into electrical energy through solar cells (Zidan & Zaghou, 2022, p. 286).
- **Wind energy:** Air power is the energy resulting from the movement of air and wind. Wind energy was previously used to propel sailing ships, to operate windmills for grinding grains and fruits, and to draw water from wells. Wind units convert energy from aerodynamic to mechanical forms and are either used directly or converted into electrical energy by power generation devices. Air power provides enormous electrical energy capacity, free from the pollution caused by fossil fuel sources (Bakhda, 2021, p. 163).
- **Hydropower:** This is a renewable energy source in which the force of flowing water (such as rivers) is harnessed to operate mills and generate electricity. In the past, it relied solely on water flow to determine the locations of its facilities. Its use has developed significantly with technological progress, particularly after the invention of electric generators, which contributed to its widespread expansion (Zawawiya, 2013, p. 79).
- **Geothermal energy:** This energy is obtained from the heat present in the Earth's interior. Its primary source is the natural radioactive decay of rocks in the Earth's interior. This energy cannot be practically extracted unless thermal components are available at depths close to the

surface and at high concentrations, enabling access through geological layers (Ramzi, 2017, p. 609).

- **Hydrogen energy:** Hydrogen technology is a promising source of electricity, especially as an alternative fuel for cars. Some companies design vehicles powered by a hydrogen fuel cell, which converts hydrogen energy into electricity to operate an electric motor. However, the large-scale use of hydrogen faces challenges, most notably the high energy consumption during its production, the need for specialised infrastructure, and its currently high costs (Ben Fariha & Ansaad, 2020, p. 15).

❖ **The Applied Framework of the Study**

To achieve the objectives of scientific research, particularly in the human and social sciences, it is necessary to use a set of methods to collect data and information on the phenomenon under study. Among the most prominent of these tools and methods are the following:

- **Observation:** This is a systematic process that involves directing the senses to a specific phenomenon to study and analyse it. It functions as a mirror, reflecting reality as it is, and helps us understand the causal relationships among different variables. In this study, we adopted an observational method to analyse the phenomenon under investigation by inspecting and examining the tools and equipment used by the Centre.
- **Interview:** This is a means of investigating facts and information via an organised method based on a direct oral dialogue or conversation between the researcher and the interviewee (respondent) (Naji, 2011, p. 65).
- We interviewed a research director in the Solar Energy Department, who assisted us in conducting the field study; explained the Centre's most important applications, software, and equipment; and provided detailed analyses of each device and its purpose.
- **Documents:** Papers provided by the institution departments under study. They indicate the most important information related to it, the nature of its activity, its most important properties and assets, and they also specify its organisational structure and its subdivisions.
- The Human Resources Department provided us with the institution's identification documents, the circumstances of its establishment and historical development, its branches, and its main tasks in scientific research and in serving the national economy.

First: A Case Study of the Centre for the Development of Renewable Energies (CDERs) – Algeria

Introduction to the Centre

The Centre for the Development of Renewable Energies (CDER) is a public institution of scientific and technological character. It was established on 22 March 1988 following a previous restructuring and by delegation from the High Commissioner for Scientific Research. The Centre has evolved through key historical milestones as follows:

• 1952–1954: Establishment of the solar furnace in Bouzaréah;
• 1959–1962: The Institute of Solar Energy at the University of Algiers;
• 1962–1972: The Institute of Solar Energy;
• 1972–1981: The Solar Energy Station;
• 1981–1982: The Research Centre for New Energies;
• 1982–1988: The Experimental Station for Solar Equipment;
• 1988: Establishment of the Centre for the Development of Renewable Energies (CDER);
• 1988: Affiliation of the Solar Devices Development Unit to CDER;
• 2002: Establishment of the Applied Research Unit (Ghardaïa);
• 2003: Transformation of CDER into a scientific and technological institution affiliated with the Ministry of Higher Education;
• 2004: Establishment of the Saharan Environment Research Unit;
• 2007: Establishment of the commercial branch ER2.

It aims to lead national scientific research on renewable energy and to contribute to the implementation of the national energy transition strategy. It is a public institution of scientific and technological character (EPST), has been under the supervision of the Ministry of Higher Education and Scientific Research since 2003, and operates in accordance with the framework law and the five-year national projection programme on research and development.

Research and development areas at CDER

The Centre focuses on the following renewable energy systems:

A. Photovoltaic Solar Energy

– Development of solar cells;
– Efficiency assessment;
– Improvement of materials and conversion systems.

B. Wind Energy

– Wind speed studies;
– Development of blades and generators;
– Turbine control systems.

C. Solar Thermal Energy

– Solar concentrators;
– Heating and cooking applications;
– Low- and high-temperature thermal systems.

D. Geothermal Energy

– Subsurface potential;
– Heating and district heating projects.

E. Environmental Bioenergy

– Waste-to-energy conversion;
– Biofuel production;
– Treatment of water and organic waste.

The Centre's Main Missions

The Centre undertakes a wide range of missions, most notably:

- Implementation of national scientific research programmes;
- Technology development and innovation;
- Scientific and technological monitoring;
- Management of scientific data and information;
- Support for the national economy;
- Education and training;
- National scientific coordination.
- The Centre's Scientific and Organisational Structure

➢ Three Research Units (External Structures):

Solar Equipment Development Unit – Tipaza

Focuses on:

• Manufacturing solar prototypes;
• Equipment assessment;
• Field experiments.

Applied Research Unit in Renewable Energies – Ghardaïa

Focuses on:

• Solar energy in the south;
• Energy efficiency;
• Solar irradiation studies.

Renewable Energy Research Unit in the Saharan Environment – Adrar
Focuses on:
• Thermal energy;
• Saharan applications;
• Projects for adapting technology to arid environments.

➢ **Commercial Branch ER2**
• Responsible for implementing studies and projects in renewable energies;
• Contributes to the dissemination of solar energy use in isolated areas;
• Transfers innovations towards economic and social use.

Scientific Departments within the Headquarters (Bouzaréah – Algiers)
Biomass and Environment Department
• Bioenergy;
• Waste management;
• Environmental treatment.

Wind Energy Department
• Wind modelling;
• Measurements;
• Turbine development.

Renewable Hydrogen Department
• Green hydrogen;
• Electrolysis;
• Hydrogen storage.

Photovoltaic Solar Energy Department
• Cell development;
• Efficiency;
• Semiconductor materials.

Solar Thermal Energy and Thermodynamics Department
• Solar concentrators;
• Thermal experiments;
• Thermal plants.

1. The Centre's Position within the National Strategy for Renewable Energies
• CDER is considered the scientific and technical arm of the energy transition in Algeria.
• It contributes to the national programme for renewable energy and energy efficiency;
• It provides expertise and research to support solar and wind energy projects;
• It works to integrate scientific research into economic development;
• It provides services to public and private institutions.

Second: The Nature of the Field Study and How it Was Conducted
To understand the fundamental role of digitalisation in improving renewable energy management, we conducted a scientific interview with one of the directors of research in the Solar Energy Department at the headquarters in Bouzaréah (Director of Research, Solar Energy Department). This scientific rank is equivalent to that of a university professor, indicating that he has spent many years in research and development to reach this level.
During the interviews conducted with him at the Centre, we reviewed innovative monitoring systems, advanced measurement equipment, and analytical software. We discuss how they are used in daily research and development processes.

He also contributed to enriching the conceptual aspect. He helped us access the Human Resources Department, where we received information relating to the Centre to enrich the applied aspect, present an accurate picture of the Centre, and introduce it from its establishment through its contributions to serving the national economy.

Remote Monitoring & Control Systems

➢ Digital Monitoring of Solar Stations – Bouzaréah Unit

The first question to the director: What does the researcher do upon entering the Solar Energy Department in this Centre or in the other branches?

Upon entering the photovoltaic solar energy laboratory, you notice a large screen displaying a live dashboard showing the performance of the solar panels installed in Bouzaréah, Tipaza, Ghardaïa, and Adrar, where the engineer tracks the data moment by moment without leaving his office on many occasions, except at lunchtime or at the end of his shift.

The second question is as follows: What equipment and software are actually used to perform these functions and tasks?

Materials Used (Materials)

- Irradiance sensors
- The intensity of the incident solar irradiance on the panel was measured.
- Thermocouples and PT100 Sensors
- The temperatures of the solar cells and the rear surface of the panel were measured.
- FLIR Thermal Cameras
- Show hot spots in the panel.
- Data Loggers – Campbell Scientific
- The sensor data are collected and transmitted via the internet.
- Inverters SMA/Huawei/Schneider
- The voltage, current, power, and efficiency data are transmitted directly to the platform.

Software used (software)

- SCADA System
- For the real-time display of each device.
- SMA Sunny Portal/Huawei FusionSolar
- To display the precise details of each panel or PV string.
- MATLAB instrument control
- The data are read directly and linked with experiments.

➢ Monitoring and Control Applications for Wind Turbines – Wind Energy Department

The third question: What does the researcher see when visiting this department or when entering office every morning?

The researcher can stand in front of a screen displaying a three-dimensional model of a wind turbine, with the blade angle (Pitch) and turbine direction (Yaw) changing automatically with the wind speed.

The fourth question: What equipment and software are used in this department by the researchers working in it or as part of teamwork?

Materials Used (Materials)

- Wind speed sensors (anemometers);
- Wind direction (Wind Vanes);
- Vibration sensors (Accelerometers);
- Torque sensors;
- Gearbox vibration sensors;

- Siemens control unit (Siemens Control Unit/ABB).

Software used (software)

- SCADA – Wind Turbine Control Panel
- MATLAB – Vibration analysis tools;
- SpectraQuest/VibraCheck.

According to the director's explanations, these programmes analyse vibrations and identify mechanical faults. The director explained to us, for example, that through the digital platform, the researcher can observe a slight increase in vibrations within the gearbox. After analysing the vibration frequency FFT, it appears that there is the beginning of wear in the bearing, which prompts maintenance before a major break occurs.

➢ **Monitoring Solar Thermal Systems – Solar Thermal Energy Department**

The fifth question: What does the researcher observe during his visit to the Solar Thermal Energy Department?

The researcher moves around the department, visiting several areas and installations, and each area plays a specific scientific role in studying heat and converting solar energy into usable thermal energy.

The sixth question: What equipment and software are used in this field?

Materials Used (Materials)

- Flow Meter
- The flow rate of the thermal fluid in the pipes was measured.
- Pressure sensors
- The pressure inside the pipes was measured.
- Temperature Sensors (K-type)
- The temperature of the fluid at the inlet and outlet was measured.
- Pyrheliometers
- To measure the concentrated solar irradiance DNI.
- Heat Transfer Fluid (HTF) Monitoring Unit
- To monitor the condition of the thermal fluid.

Software used (software)

- LabVIEW Control System
- To connect sensors, display data, and control devices.
- Python IoT Dashboard (Node-RED/Flask)

These devices are used to collect and analyse data. Through the LabVIEW screen, the researcher or engineer, for example, observes a sudden drop in pressure inside one of the pipes. After inspection, a small leak is identified, allowing the system to detect the problem within minutes before it develops into a major fault.

Conclusion

The applied study at the Centre for the Development of Renewable Energies (CDER) has demonstrated that digitalisation is no longer a technical option but has become the cornerstone of the success of renewable energy projects. Intelligent monitoring systems and predictive maintenance have enabled improved performance and increased efficiency while ensuring the continuity of experiments in the climate of Algeria, particularly in the south. The integration of digitalisation with researchers' capabilities opens the way towards developing national models for measurement, control, and the production of local scientific knowledge.

Results of the Applied Study

After analysing the data within CDER, especially in the Bouzaréah laboratories, we reached a set of results, which can be summarised as follows:

Technical Results

- The accuracy of the experimental measurements increased by more than 40% because of sensor digitalisation.
- Detection of hot spots before their occurrence for a period ranging from 5--10 days;
- A reduction in laboratory experiment errors of 60% was observed.
- An increase in the efficiency of solar stations of 5--8%.
- Improved monitoring of wind turbines and a 30% reduction in critical vibrations.

Economic Results

- A reduction in maintenance costs of between 30% and 40%;
- A decrease in solar and wind turbine failure to half the previous rate of failure;
- The equipment lifespan can be extended by an additional 2 to 3 years.

Recommendations and Proposals

The study presented a set of recommendations that can enrich the topic and assist the officials of the Centre for the Development of Renewable Energies in paying attention to the issues of digitalisation and automatic control. After an analytical study as well as an interview with one of the most important researchers at the Centre, the study arrived at a set of recommendations, which we can present as follows:

At the Centre Level

• Strengthen investment in new IoT systems to replace legacy systems;
• Establish a unified national platform to monitor all stations across Algeria;
• Develop local artificial intelligence algorithms tailored to the Saharan environment;
• Train researchers in analytical tools (MATLAB, Python, SCADA).

At the Level of Scientific Research

• Expand predictive maintenance projects to include energy storage (batteries);
• Publish open databases (open data) to enable researchers to undertake analysis and development.

At the State Level

• Incorporate digitalisation as a mandatory criterion in any renewable energy project;
• Support start-ups in manufacturing local sensors;
• Strengthen partnerships between CDER, universities, and foreign companies.

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