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RESEARCH ARTICLE

EXPLORATORY STUDY OF TEACHING AND LEARNING ENERGY TRANSFER IN PHOTOVOLTAIC ENERGY CHAINS IN TECHNICAL AND VOCATIONAL EDUCATION: DIDACTIC PERSPECTIVES

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ABSTRACT

This research falls within the field of physics education and focuses on the teaching and learning of energy transfers in photovoltaic energy chains within technical and vocational education in Benin. It begins with the observation that energy education is marked by three major tensions: conceptual, concerning the definition and coherence of school scientific models; didactic, relating to the transposition and articulation between theory and practice; and socio-professional, linked to sustainability, employability, and youth integration. Solar energy, although a central concept, remains abstract and difficult to teach, especially when it comes to designing and implementing transfers and conversions in photovoltaic systems. From an epistemological perspective, photovoltaic energy chains are analyzed as systemic models that represent energy flows and transformations, including conversion and storage components, architectures (on-grid, off-grid, hybrid), and their didactic implications. The theoretical framework draws on professional didactics and the double didactic-ergonomic approach (DADE), aiming to connect conceptual, functional, and organizational dimensions of teaching. The methodology is based on semi-structured interviews with professional teachers, allowing triangulation to identify difficulties in teaching and learning solar photovoltaics. The results show that learners struggle to distinguish between power and energy, to understand cumulative losses, and to interpret performance indicators. They also face epistemological obstacles, such as the inadequate transfer of reasoning from classical electricity and the gap between theoretical sizing and field realities. Teachers, for their part, encounter difficulties in explaining complex notions such as Maximum Power Point Tracking (MPPT), AC/DC architectures, or battery management, and must constantly update their content. On the organizational level, they suffer from a lack of harmonized references, pedagogical and material resources, and insufficient articulation between theory, practice, and fieldwork. Finally, they are confronted with incomplete input data, local constraints, and an insufficient regulatory framework.

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INTRODUCTION

In the Beninese context, marked by a chronic energy deficit despite abundant solar potential, the teaching and learning of energy transfers in photovoltaic energy chains constitutes a strategic issue. Integrating these systems into school and professional curricula appears indispensable to meet qualification and employability needs, while contributing to international energy transition objectives. Sustainable Development Goal (SDG) 7, climate conferences (COP21–COP28, Kyoto agreements, Dubai Conference 2023), and Nationally Determined Contributions impose ambitious renewable energy strategies on states. At the same time, SDG 4, target 4, places the development of technical and vocational skills at the heart of UNESCO's Education 2030 agenda. However, energy teaching remains marked by conceptual, didactic, and socio-professional tensions. The concept of energy and its transfer is difficult to teach and learn, and curricula related to photovoltaics suffer from gaps, lack of harmonization, and weak contextualization. In Benin, secondary programs ignore solar systems, while vocational and higher education programs show shortcomings in design, sizing, and maintenance of photovoltaic installations.

This research aims to analyze the specific determinants of teaching and learning energy transfers in photovoltaic energy chains within technical and vocational education. It seeks to identify obstacles and conditions for appropriation, in order to propose an epistemological reference model likely to improve training and skill acquisition in this field.

ENERGY TRANSFER IN PHOTOVOLTAIC ENERGY CHAINS AND DIDACTIC ISSUES

Brief History of Solar Energy: Solar energy has undergone a remarkable evolution, moving from a scientific curiosity to a cornerstone of the global energy transition. Since Antiquity, humankind has sought to harness the power of the sun, as illustrated by accounts of Archimedes' mirrors. The true breakthrough came in 1839 with Edmond Becquerel, who demonstrated the photovoltaic effect. This foundational principle paved the way for the first solar cells, from Fritts' selenium cell (1883) to the silicon cell developed at Bell Laboratories (1954). Einstein's theory of the photoelectric effect (1905) consolidated this advance. In the 1950s–1960s, the space race gave solar energy a strategic dimension: the Vanguard satellite (1958) was powered by solar panels, proving their reliability under extreme conditions. The oil crisis of 1973 exposed dependence on fossil fuels and accelerated interest in solar energy. As early as 1974, buildings entirely powered by solar energy appeared. From the 2000s onward, incentive policies in Germany and Japan triggered a spectacular drop in costs. In Europe, solar now accounts for about 11% of electricity production, surpassing coal. In Benin, consumption remains low (130 kWh per capita in 2023 compared to 3,771 kWh globally), with solar representing only a marginal share (1.6%) despite considerable potential. In France, solar power has expanded rapidly since 2009, reaching 31.3 GW of installed capacity in 2025**.**

Principe et description de la chaîne énergétique photovoltaïque: A photovoltaic energy chain describes the pathway of energy from solar radiation to the service delivered by an electrical receiver. It highlights the sources, converters, transfers, and losses. Solar radiation constitutes the input energy; the photovoltaic module ensures conversion into direct current, which can either be used directly, stored in a battery via a charge controller, or transformed into alternating current by an inverter. Thus, the simplified material representation of a photovoltaic energy chain (PEC) is: Solar radiation → PV module → Charge controller → Battery → Inverter → Receiver. The distinction between transfer and conversion is essential: transfer corresponds to the movement of energy without a change in form, whereas conversion refers to the transformation of one form of energy into another. Each component generates losses—whether thermal, optical, or related to conversions—and the overall efficiency (η_{global}) of an installation is the product of the partial efficiencies of each element.

$$\eta_{global} = \eta_{module} \times \eta_{controller} \times \eta_{battery} \times \eta_{inverter} \times \eta_{wiring}$$

From a didactic perspective, the energy chain constitutes a pedagogical tool that enables learners to identify energy sources, distinguish forms and conversions, understand the notion of losses, and develop proportional reasoning skills through efficiency calculations. The teacher can thus propose a progressive approach, ranging from the simple description of a panel powering a lamp to the elaboration of a complete chain integrating dissipations, thereby fostering structured understanding and avoiding the reduction of the diagram to a mere graphic exercise.

Technological Components and Architecture of Photovoltaic Systems: The technological components of a photovoltaic energy chain mainly include the charge controller, the battery, and the inverter, each playing a decisive role in overall performance. The charge controller, whether PWM or MPPT, regulates the battery charging conditions and optimizes the use of solar energy. PWM controllers, simple but limited, provide efficiencies of 60 to 75%, while MPPT controllers, more efficient, reach 90 to 95% and allow the panels to operate at their maximum power point. The battery ensures electrochemical storage, with round-trip efficiencies ranging from 70 to 85% for lead-acid batteries and 90 to 95% for lithium-ion batteries, illustrating the notion of reversible conversion—often misunderstood by students. The inverter converts direct current into alternating current, synchronizes the energy injected into the grid, and provides protection functions, with efficiencies close to 98% under optimal conditions. The entire system is subject to multiple losses: thermal, irradiance, soiling, shading, wiring, or conversion. These losses reduce the available useful energy and must be identified to establish a realistic balance. From a didactic perspective, the study of these components and their efficiencies helps illustrate fundamental concepts such as the optimal operating point, reversible conversion, or energy conservation, while confronting theoretical data with real measurements. This strengthens learners' understanding and their ability to connect models with reality.

One mainly distinguishes between grid-connected (on-grid) architectures and stand-alone (off-grid) systems. On-grid systems, suited to urban areas, display overall efficiencies of 75 to 85% excluding module losses, and allow the direct injection of the energy produced into the grid. Off-grid systems, predominant in rural settings, integrate a charge controller and a battery to ensure storage and energy autonomy, but their overall efficiency is lower, around 55 to 65%, due to additional losses linked to storage and regulation. Each architecture responds to specific socio-economic contexts: grid-connected systems are appropriate in environments with a reliable electricity network, whereas stand-alone systems are essential in areas not served by the grid. From a didactic perspective, the diversity of architectures illustrates the relationship between technological choices and local needs, particularly in Benin where limited grid access necessitates autonomous solutions. Comparative study of the systems fosters understanding of technical constraints, maintenance and durability issues, as well as optimization prospects. It enables learners to connect theoretical concepts of efficiency and conversion with the practical realities of rural electrification and energy transition, thereby reinforcing the relevance of teaching and anchoring knowledge in concrete situations. Energy transfer in photovoltaic chains illustrates a pathway rich in conversions and losses, yet endowed with major didactic potential. The history of solar energy bears witness to scientific perseverance, while the description of energy chains enables the articulation of theory and practice. The technological components (controller, battery, inverter) provide concrete examples for teaching complex notions such as efficiency, reversible conversion, or optimal operating point.

Finally, the typology of systems (on-grid vs. off-grid) contextualizes teaching according to local realities, notably in Benin.

THEORETICAL FRAMEWORK

This study is situated within a dual perspective that articulates the theory of conceptualization in professional didactics and the theory of the double didactic and ergonomic approach (DADE). The theory of conceptualization in professional didactics Building on the work of Piaget (1974) and Vergnaud (1994, 1996), conceptualization is understood as a dynamic process in which learning relies on reflective abstraction and the transformation of action schemes through assimilation and accommodation. Vergnaud, through his theory of conceptual fields, shows that every concept mobilized in complex professional situations—such as the design and implementation of photovoltaic solar systems—comprises three inseparable dimensions: reference situations, forms of representation (language, symbols, diagrams), and operative invariants that implicitly guide action. Learning is therefore not limited to acquiring abstract definitions but involves repeated confrontation with varied situations that enable concepts to be structured into conceptual fields.

Professional didactics (Vinatier, 2011, 2013) draws on this theory to analyze work and design training systems. It highlights action schemes and underlying operative invariants in order to transform implicit knowledge into transmissible knowledge. Work analysis thus becomes a learning instrument that fosters practitioners' reflexivity and the articulation between theory and practice. Initially developed in the industrial field, this approach has expanded to services and education, where it contributes to making implicit skills visible and to developing durable knowledge from real work situations, such as those related to photovoltaic systems. The double didactic and ergonomic approach (DADE) Developed by Robert and Rogalski (2002), DADE provides a relevant framework for analyzing teaching practices. To describe and justify these practices, we draw on the double didactic and ergonomic approach, which considers teachers' practices as encompassing everything a teacher "thinks, says or does not say, does or does not do, over a long period of time, before, during, and after class" (Robert, 2008). The didactic approach highlights the tasks proposed to students and their modes of implementation, while the ergonomic approach introduces the institutional, personal, and social constraints that influence teachers' activity. This dual perspective makes it possible to understand the tensions between curricular prescriptions, institutional conditions, and actual practices. It sheds light on the obstacles encountered in teaching scientific concepts, linking difficulties inherent to knowledge itself with constraints experienced by teachers. DADE is thus particularly useful for analyzing resistance to the implementation of pedagogical and technological innovations and for proposing adapted training pathways.

LITERATURE REVIEW AND RESEARCH PROBLEM

State of the Art on Teaching and Learning Energy Transfer in Photovoltaic Chains at Secondary Level: The teaching of energy in middle and high school is marked by conceptual and didactic difficulties. Traditional approaches, centered on a mechanical and quantitative definition of energy, have been criticized for their reductive character (Lehrman, 1973; Arons, 1990). Students struggle to connect their intuitive conceptions with abstract formulations (Solomon, 1992; Driver et al., 1994). To overcome these limitations, several researchers propose progressively linking qualitative representations with scientific models. Lemeignan and Weil-Barais (1990, 1993) developed teaching devices based on the construction of energy chains, while Tiberghien and Megalakaki (1995) introduced the "seed model" as a transitional tool. Halbwachs (1973) emphasized that simple causal reasoning can serve as a foundation. Innovative curricula focused on energy conservation (Haber-Schaim, 1983; Shadmi et al., 1978) or integrating a social dimension (Agabra et al., 1979) aim to provide a coherent and inter-phenomenological vision. More recent research highlights the fundamental properties of energy and persistent confusions (Watts, 1983; Trumper, 1998; Pintó et al., 2005). Tison (2023) points out the absence of a stabilized school model and inconsistencies between prescriptions and practices. Recommendations converge toward progressive, multidisciplinary learning centered on modeling, with continuous training playing a crucial role.

Studies on the teaching of photovoltaic solar energy remain limited. Zagaré and Kalifa (2024), in Burkina Faso, show that most teachers come from related fields and lack specific training. Curricula appear inadequate, continuing education is rare, and didactic materials are insufficient. Their study highlights an imbalance between theory and practice and proposes revising content, increasing practical modules, and enhancing teacher involvement. At the higher education level, Jaouen et al. (2008) propose an experimental didactic approach adapted to electrical engineering. Their research, situated in the context of energy transition, analyzes the impact of temperature and real conditions on photovoltaic panel efficiency. Results show a significant decrease in open-circuit voltage with rising temperature, confirming the relevance of cogeneration. Amorphous panels, less efficient but easier to produce, contrast with crystalline panels, more effective but costly in materials and energy. This experimental approach illustrates the relevance of teaching focused on energy optimization and ecological awareness, linking pedagogical practices with the challenges of energy transition.

The literature review highlights a strong connection between research on teaching energy at the secondary level and that on photovoltaic solar energy. The former emphasizes conceptual difficulties related to didactic transposition, the need for methodological progression, and the importance of modeling through energy chains to overcome students' intuitive conceptions. The latter reveals organizational and curricular obstacles, notably the lack of specific teacher training, insufficient material resources, and the mismatch between theory and practice. These findings converge toward a common requirement: to conceive the teaching of energy as a global process, articulating scientific rigor, didactic relevance, and integration into contemporary socio-economic issues. Energy, particularly solar photovoltaic, thus emerges as a unifying concept and a learning object with social and professional purposes, conditioning the success of the energy transition and the training of competent technicians.

Research Problem: The problem addressed in this study arises in a context where the teaching and learning of energy transfers in photovoltaic energy chains in Benin has become a crucial issue. Despite the abundance of solar potential,

Sub-Saharan Africa continues to face a chronic energy deficit that hampers economic and social development. The integration of photovoltaic systems into school and vocational curricula thus appears as a strategic necessity to meet the challenges of training and employability. The central problem is to characterize the modalities of teaching and learning these energy transfers, in order to highlight the obstacles and determinants that influence their appropriation by teachers and learners. This problem unfolds across several complementary dimensions. Politically and internationally, Sustainable Development Goal No. 7 adopted by the United Nations in 2015 emphasizes universal access to sustainable and modern energy, while climate commitments and Nationally Determined Contributions require states to adopt ambitious renewable energy strategies. Socio-economically, dependence on hydrocarbons and successive energy shocks reinforce the need for local solutions, while the energy deficit limits productive activities. Educationally, SDG No. 4 and UNESCO's Education 2030 agenda emphasize the development of technical and vocational skills as an essential condition for employment and entrepreneurship. In the context of secondary education, the representation of an energy chain is embedded in learning related to sources, forms, transfers, and conversions of conventional energy. Physics, chemistry, and technology curricula at the secondary level (Study Program Guide, Grade 9, 2020) provide for the progressive introduction of different forms of energy—gravitational, kinetic, chemical, thermal, electrical, nuclear, and luminous—through concrete contexts of transfer and conversion. However, they remain silent on the specific case of solar energy. The experimental realization of a conversion device and its description through an energy chain are also among the expected learning outcomes at this level. The analysis of curricula in technical and vocational education reveals the coexistence of diverse training programs developed according to different methodological approaches, often unharmonized or not implemented. Finally, from a didactic perspective, previous research shows that the teaching of energy is marked by conceptual, didactic, societal, and professional tensions. The concept of energy and its transfer remains difficult to teach and to learn, while curricula related to photovoltaics suffer from gaps, lack of harmonization, and weak contextualization.

Within this framework, the objective of the research is to analyze the specific determinants of teaching and learning energy transfers in photovoltaic energy chains within technical and vocational education in Benin. The ambition is to propose an epistemological reference model likely to improve training and facilitate the acquisition of skills necessary for the design, installation, and maintenance of photovoltaic systems. Two questions guide this approach: on the one hand, what characterizes the teaching of energy transfer in photovoltaic chains in Benin, and on the other hand, what characterizes the learning of this transfer by students? These questions aim to shed light on the difficulties encountered by teachers and the obstacles faced by learners, in order to identify pathways for better appropriation of knowledge and skills related to photovoltaics.

RESEARCH METHODOLOGY

Data Collection: Data collection was based on a panel of ten professional teachers selected according to rigorous criteria ensuring their expertise in photovoltaic (PV) solar energy. The selected individuals were required to hold at least a Master's degree, to have a specialization in the design and implementation of PV solar systems, a minimum of seven years' experience in teaching solar energy—five of which in the design and installation of PV systems—and to be regularly active in technical or higher education institutions.This panel was drawn from four higher education institutions, four technical and vocational high schools, and one public vocational training and apprenticeship center. Participants were also involved in companies specializing in PV solar energy in Benin and Togo, which reinforced the relevance of their testimonies. Their dual status as teachers and practitioners conferred particular legitimacy to their contributions, given their initial training, professional experience, and affiliation with recognized institutions in the field.

The data collection technique consisted of semi-structured interviews conducted individually with each panel member. The interview guide comprised two sections: the first focused on teaching and learning photovoltaic energy chains (PECs), and the second on professional practices related to the design and implementation of solar systems. The first part aimed to gather the difficulties encountered in transmitting and understanding technical concepts, as well as epistemological, organizational, and functional obstacles. The second part sought feedback from practitioners of PV solar energy, emphasizing technical dimensions and field constraints. To frame the responses of each interviewee, we specified the precise technical concepts on which they were asked to express what they "think, say or do not say, do or do not do, over a long period of time, before, during and after class" (Robert, 2008). By drawing on their extensive experience in teaching and training in PV solar energy and in implementing solar energy projects, we assumed that the professional teachers interviewed were able to describe their work environment and highlight the problems they encounter. This approach was embedded in professional didactics, enabling real experience to be transformed into teachable skills and making implicit knowledge visible. The interviews were recorded and fully transcribed to preserve the authenticity of the participants' statements.

Data Processing and Analysis Methodology: Data processing relied on verbatim transcription of the interviews, carried out according to conventions recognized by the scientific community. This step preserved the richness of the discourse and ensured a faithful analysis of the representations and practices of professional teachers. The analysis then employed a triangulation approach inspired by Lessard-Hébert, Goyette and Boutin (1997). Participants' responses were cross-checked and compared for each category of questions in the interview guide, in order to highlight regularities and individual specificities. This approach made it possible to identify the main problems related to teaching and learning energy transfers in PECs, distinguishing conceptual difficulties (understanding notions of energy, power, or losses, mastering advanced electrotechnical concepts), organizational obstacles (time allocation, theory/practice articulation, access to material and software resources), and functional constraints (absence of a harmonized reference framework, divergences between academic and field approaches).Furthermore, the analysis of practitioners' feedback on PV solar energy shed light on technical and contextual challenges such as the quality of input data, the impact of local climatic conditions, the availability and cost of equipment, difficulties in financing and project

bankability, as well as maintenance and performance monitoring requirements. All these elements were organized into thematic tables to synthesize the obstacles encountered and to link pedagogical dimensions with professional realities. Thus, the adopted methodology made it possible to cross academic and practical perspectives, to account for tensions between theoretical knowledge and field constraints, and to identify pathways for improving the teaching and learning of energy transfers in photovoltaic chains in Benin.

RESULTS

The results obtained from the triangulation of observations of the personal component of the professional teachers interviewed highlight conceptual and epistemological difficulties among learners, as well as conceptual, functional, and organizational difficulties among the teachers observed.

Conceptual Difficulties Observed Among Learners Regarding Energy Transfer in PECs: Learners face numerous confusions in understanding photovoltaic energy chains. They equate peak power (STC) with constant production, without grasping the non-linear nature of the PV generator. They struggle to distinguish between power (W) and energy (Wh), and to relate instantaneous power to energy produced over time. The notion of cumulative efficiency is poorly understood: some add losses instead of multiplying them, while others ignore them altogether. Invisible losses (temperature, shading, wiring, soiling) are difficult to conceptualize, and their prioritization remains problematic. Performance indicators, such as the performance ratio, are confused with module efficiency, making monitoring data interpretation complex. Finally, the distinction between irradiance and irradiation, as well as GHI/DHI/DNI/POA components, is not mastered, leading learners to attribute any drop in production to system faults rather than normal variations.

Epistemological Obstacles Among Learners Regarding Energy Transfer in PECs Learners: transpose reasoning from classical electricity to photovoltaics without considering solar variability, MPPT, or battery state of charge. Similarly, they apply thermal reasoning to PV production, believing that heat increases output, without understanding the negative effect of temperature on Pmax. The dissociation between theoretical sizing and field reality constitutes another obstacle: academic calculations are not connected to practical contingencies such as dust, aging, or module orientation.

Conceptual, Functional, and Organizational Difficulties Observed Among Teachers: Teachers themselves encounter conceptual difficulties, particularly in explaining technical quantities related to MPPT, AC/DC architectures, and hybrid inverters. Battery bus management (voltage, SoC, DoD, balancing) is complex, and the rapid evolution of technologies requires constant content updates. Functionally, the absence of a harmonized reference framework among schools and teachers creates heterogeneity in practices. The lack of pedagogical continuity, the absence of a shared resource bank, and divergences between academic and field approaches exacerbate difficulties. Organizationally, insufficient teaching hours, limited material and software resources, and weak infrastructures (power outages, limited computer facilities) hinder instruction.

Practical Difficulties in Implementing PV Systems: The actual implementation of PV systems reveals additional obstacles. Input data are often incomplete or unrepresentative, and local climatic conditions (dust, harmattan, soiling) strongly affect performance. Equipment availability and cost, dependent on imports, constitute a major barrier. Financing is difficult, subject to heavy banking constraints. The regulatory framework remains incomplete, with scattered standards and no mandatory installer qualification. Preventive maintenance is insufficient, and budgetary trade-offs sometimes lead to under-sizing, undermining system reliability.

As shown, the results highlight the complexity of difficulties encountered by both learners and teachers, as well as the practical and institutional constraints that hinder the teaching and implementation of photovoltaic energy chains.

DISCUSSION

The results of our survey of professional teachers confirm and extend findings already established in the literature on the teaching of energy and PECs.

Conceptual Difficulties of Learners: The confusions identified (power vs. energy, cumulative efficiency, irradiance vs. irradiation) echo the observations of Feynman (1980) and Lehrman (1973) on the abstract nature of the energy concept and the difficulty of linking formal quantities to concrete phenomena. Reeves (1981) proposed a monetary analogy that sheds light on learners' tendency to add efficiencies instead of multiplying them: they perceive energy as a "sum" rather than a flow subject to successive losses. These obstacles show that scientific formalization (law of conservation, efficiency principle) remains difficult to transpose into school practices.

***Epistemological Obstacles*:** The inadequate transfer of reasoning from classical electricity to photovoltaics confirms Halbwachs' (1980, 1981) analyses on the historical construction of the energy concept: learners mobilize thermal or mechanical schemas without integrating PV specificities (solar variability, temperature coefficient). Likewise, the dissociation between theoretical sizing and field reality illustrates the tension highlighted by Meyerson (1907): energy is an abstract quantity, but its practical use depends on local conditions and material constraints.

***Teachers' Difficulties*:** Teachers themselves face obstacles in explaining complex notions such as MPPT or AC/DC architectures. This aligns with the findings of the Council for Science and Society Report (1979) on the difficulty of teaching reversibility and energy distribution: technical quantities evolve rapidly and require constant updating. Teachers must therefore articulate scholarly knowledge and taught knowledge, a process described by Chevallard (1991) as didactic transposition.

***Functional and Organizational Problems*:** The absence of a harmonized reference framework and a shared resource bank confirms Robert & Rogalski's (2002) analyses within the DADE framework: teaching practices are fragmented, subject to ergonomic and institutional constraints. The divergence between academic and field approaches illustrates the difficulty of articulating didactic and professional dimensions, limiting the coherence of learning.

Practical Difficulties in Implementation: Obstacles related to input data, local climatic conditions, and financing echo findings from earlier research on PV systems (cf. Boltzmann, 1870; Gibbs, 1900 on thermodynamic limits; Lavoisier-Laplace on dependence on experimental conditions). These constraints show that teaching PECs cannot be limited to a theoretical approach: it must integrate socio-economic and regulatory realities.

In summary, the results of our study confirm that the difficulties encountered in teaching and learning PECs are simultaneously conceptual (abstraction of the energy concept), epistemological (inadequate transfer of knowledge), didactic (complex transposition of technical notions), and organizational (absence of harmonized reference frameworks). These findings extend the analyses of Feynman, Reeves, Halbwachs, Meyerson, and Chevallard, and underscore the need for a multi-didactic approach articulating scientific knowledge, professional practices, and institutional constraints.

CONCLUSION

The exploratory study conducted on the teaching and learning of energy transfers in photovoltaic energy chains (PECs) in Benin highlights conceptual, didactic, and socio-professional tensions that hinder the appropriation of this field by teachers and learners. The difficulties identified—confusion between power and energy, epistemological obstacles linked to the transfer of classical reasoning, complexity of technical notions such as MPPT or battery management, lack of harmonized reference frameworks and pedagogical resources—reflect an urgent need to rethink training systems.Beyond this observation, the research opens up an essential perspective: to better invest in this vast field while designing an Epistemological Reference Model for the teaching of PECs. Such a model would clarify fundamental concepts, articulate theory and practice, contextualize content according to local realities, and strengthen teachers' continuous training. It would provide a structuring framework to overcome curricular inconsistencies, minimize didactic losses, and promote better integration of technical and professional knowledge. Ultimately, the development of this model constitutes a strategic condition for fostering teaching and learning of PECs capable of meeting the challenges of energy transition, employability, and youth integration. It represents a pathway for consolidating pedagogical and professional practices, ensuring that solar energy—an abundant yet still under-exploited resource—becomes a sustainable lever for training and development.

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