Clean Energy Technol J, Vol. 2, No. 1, pp. 1-7, June, 2024

Clean Energy Technologies Journal
Web page info: https://cetj.yildiz.edu.tr
DOI: 10.14744/cetj.2024.0001

CLEAN ENERGY TECHNOLOGIES JOURNAL

Research Article

Design of an efficient laser diode driver with single stage power factor correction

Ahmet Yiğit SARI[1,*], Ali Rıfat BOYNUEĞRİ[1,2]

[1]*Department of Electrical Engineering, Yildiz Technical University, Istanbul, Türkiye*
[2]*Clean Energy Technologies Institute, Yıldız Technical University, Istanbul, Türkiye*

ARTICLE INFO

Article history
Received: 27 April 2024
Accepted: 31 May 2024

Key words:
Laser Diode Driver; Laser Power; LLC Resonant Converter; Transmission; Power Factor Correction; Transmission; Wireless Power.

ABSTRACT

Laser power transmission (LPT) has emerged as an innovative technology revolutionizing long-distance wireless power delivery. The efficiency of an LPT system significantly relies on the performance of the laser diode (LD) driver. This paper introduces an innovative single-stage AC-DC LLC converter with power factor correction (PFC) designed for LD drivers, addressing the specific demands of LDs. The proposed system achieves exceptional operational metrics, including high efficiency and minimal harmonic distortion in the input current. Through meticulous design and evaluation, the system demonstrates its capability to meet the intricate demands of LDs while maintaining minimal current ripple, marking a significant advancement in LPT technology. Furthermore, this study underscores the importance of LD driver efficiency by showcasing a single-stage AC-DC LLC with PFC converter that achieves an outstanding efficiency of 95.44% alongside a minimal current total harmonic distortion (THD) of 2.53%. This research represents a pivotal step toward enhancing LD driver efficiency within the domain of LPT, promising extensive applications in wireless power transmission

Cite this article as: Sarı AY, Boynueğri AR. Design of an efficient laser diode driver with single stage power factor correction. Clean Energy Technol J 2024;4:1:1–7.

INTRODUCTION

In recent years, Wireless Power Transmission (WPT) technology has experienced notable advancements, facilitating the transfer of energy without the necessity for physical or electrical interconnections between two points [1,2]. This technology has garnered significant interest in both industrial applications and consumer electronics. Compared to traditional power transmission methods, Wireless Power Transfer (WPT) offers numerous advantages such as reliability, durability, aesthetic design, originality, and ease of use.Consequently, WPT technology has begun to be utilized in a wide range of applications, from mobile devices to electric vehicles [3-5].

Highlights

- Enhances efficiency with ZVS
- Ensures 2.53% current THD
- Single-stage configuration eliminates extra switches
- Meets specific voltage and current requirements of laser diode accurately

Various methodologies exist for WPT, encompassing inductive power transfer, capacitive power transfer, microwave power transfer, and laser power transmission (LPT) [6-8]. LPT technology emerges as a promising choice for WPT, especially in the context of mobile devices like un-

***Corresponding author:**
*E-mail address: yigit.sari@yildiz.edu.tr

manned aerial vehicles and robots [9]. This technology enables uninterrupted power transfer over considerable distances, spanning several kilometers, facilitated by a high-power density laser beam [10,11].

At recent studies, laser diode (LD) has become crucial for LPT applications. Their efficiency and compact design have made them a favoured option in the field of LPT. One of the most critical challenges for LPT is the efficiency of LD [12]. The LD driver circuit plays a crucial role within the system, impacting both laser performance and overall system efficiency [13]. In LD driver circuits, linear current regulators are commonly preferred [14]. However, this method results in efficiency losses. Buck and boost converters, widely used topologies, offer an effective solution to this efficiency challenge. To meet LD requirements, researchers have driven the LD by connecting a buck converter, providing the DC component of the current, in parallel with a bidirectional converter, supplying the AC component. They achieved an efficiency of 88% at an average output power of 20 W [13]. Another significant challenge arises from LD being a current-driven device, leading to current ripples. LD demand a stable driving current, and low-ripple current is crucial [15]. A single-stage converter based on an advanced design was utilized, employing an LCL filter to reduce LD current ripples. While the circuit was documented to achieve high efficiency, no specific efficiency value was provided [16]. There are several relevant studies focusing on efficiency and current ripples, all of which primarily concentrate on DC-DC converters. However, there aren't enough studies into an AC-DC LD driver circuit. Since DC-DC converters are used between low voltage differences, different types of converters were chosen, but the LLC operating principle is advantageous in terms of high efficiency and wide input voltage range [17]. The LLC resonant converter features the advantage of zero-voltage switching (ZVS) operation, which enhances conversion efficiency and reduces electromagnetic interference (EMI) [18]. This feature has garnered significant attention in both research and various applications [19-21]. The LLC resonant converter's inherent ability to achieve high voltage gain under light loads and low voltage gain under heavy loads facilitates input current shaping across a wide voltage range [22]. This characteristic aligns with the traits of a PFC converter, emphasizing its significance in power factor correction (PFC) [23]. Consequently, the LLC resonant converter proves highly suitable for direct single-stage AC-DC conversion [24-25].

In this study, a high-efficiency LLC resonant converter with integrated grid PFC, low current total harmonic distortion (THD), single-stage operation, and ZVS at high powers has been employed to increase system efficiency. The LLC converter operates with a lower voltage, relative to the input voltage, and high current, facilitating soft switching, supplying of LD demands.

System Description

As mentioned above, achieving high efficiency and minimizing current ripple is crucial when driving LD. To supply LD demand, a highly efficient LLC-based isolated single-stage PFC converter is employed. The proposed LD driver circuit diagram is shown in Figure 1.

Proposed LD driver circuit diagram. The driver circuit comprises the input rectifier, input filter, LLC inverter, LLC resonant tank, transformer, output rectifier, and output filter. In the input rectifier section, S1-S4 switches, forming a full bridge configuration, are utilized to ensure synchronous rectification.Implementation offull bridge synchronous rectification instead of a diode bridge significantly reduces conduction loss. At the input filter stage, L_{in} and C_{in} are utilized to filter the rectified input current.At the LLC inverter part Q1-Q4 switches are convert to DC wave to high frequency AC wave and at the suitable operation conditions, ZVS feature achieved by LLC inverter part. Resonant capacitance C_r, resonant inductance L_r and the transformer's magnetizing inductance L_m together constituting LLC resonant tank. The resonant tank enables the circulation of high-frequency and sinusoidal voltage, enables the transmission of energy to the load through the transformer. At the output rectifier part there are SR1-SR2 switches constitutes full wave rectifier to convert AC voltage to DC voltage. The substitution of a full-wave rectifier in place of a full bridge rectifier results in decreased conduction losses-by reducing the required switches from four to two. This implementation is only achievable by utilizing a center-tapped transformer, making the center-tapped transformer the selected component for the circuit.In the outputfilter section, L_o and C_o are utilized to effectively filter the output current, meeting the specific requirements necessary for supplyingthe LD demands. The output filter section is crucial due to the specific demands of LD.

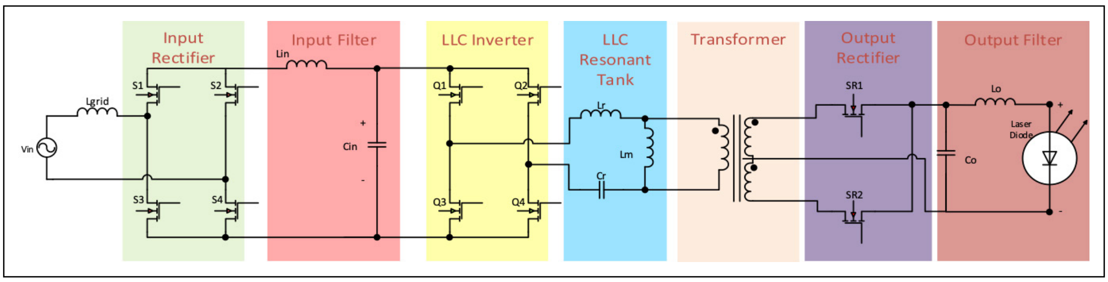

Figure 1. Proposed LD driver circuit diagram.

Calculations

There are three operational region of LLC converter, capacitive, inductiveand resistive region. Operating at capacitive, inductive or resistive region is depend onf_s switching frequency and f_p critical resonant frequency, which is formulized at Eq. 1.Additionally, as indicated in Eq. 2, the M value depends on the switching frequency f_s. M represent the voltage gain of the LLC circuit and, together with the conversion ratio of the transformer, determines the ratio of the input voltage to the output voltage.In conjunction with the determination of appropriate frequency range of LLC inverter, the LLC circuit topology significantly reduces switching losses through ZVS and operate at inductive region. If the appropriate frequency range cannot be determined, the LLC circuit operates in the capacitive region, leadingto the forfeiture of its ZVS feature and causing switching losses. Consequently, operating in the capacitive region results in an efficiency loss.It is clear that the LLC gain value must change simultaneously with the change of the input voltage. In AC-DC PFC applications, LLC's operating point is continuously altering because of the input voltage's (AC Grid's) characteristic.

$$f_p = \frac{1}{2.\pi\sqrt{(L_r + L_m)C_r}} \quad (1)$$

$$M_{LLC\_total}(f_s, \theta) = \frac{1}{2n} \cdot \frac{1}{\sqrt{\left[1 + \frac{1}{Y}\left(1 - \frac{f_r^2}{f_s^2}\right)\right]^2 + 4(sin(\theta)^4\left[\left(\frac{f_s^2 - f_r^2}{f_s \cdot f_r}\right)Q_{full\_load}\right]^2}} \quad (2)$$

$$Q_{full\_load} = \frac{\pi^2}{8n^2} \cdot \frac{I_{out}}{V_{out}}\sqrt{\frac{L_r}{C_r}} \quad (3)$$

$$f_r = \frac{1}{2.\pi\sqrt{L_r C_r}} \quad (4)$$

$$n = \frac{N_p}{N_s} \quad (5)$$

Q is the quality factor as specified in Eq.3, f_r is the resonant frequency as show in Eq. 4,n is the turn ratio of the transformer as indicated in Eq. 5,Y is the ratio of magnetizing inductance L_m to resonant inductance L_r, as expressed in Eq. 6. As depicted in Eq. 2, M varies with θ's changes because θ represents the phase angle of the input voltage, and this angle undergoes time-dependent variations. As a result, f_s is consistently changing to adjust to meet the load's requirements, adapting despite variations in the phase angle. It is crucial to avoid operating at the capacitive region due to the operational traits of the LLC circuit at capacitive region. Preventing this operation depends on factors such as the gain curve M, f_s, L_m, L_r, and the critical resonant frequency, f_p. Critical resonant frequency f_p is occurring when components L_m, L_r and C_r resonate together, acts as the critical threshold to prevent the LLC circuit from operating at the capacitive region.

$$Y = \frac{L_m}{L_r} \quad (6)$$

$$M_{LLC\_total}(f_p, \Theta) = \frac{1}{2n} \cdot \frac{1}{\sqrt{\left[1 + \frac{1}{Y}\left(1 - \frac{f_r^2}{f_p^2}\right)\right]^2 + 4(sin(\Theta)^4\left[\left(\frac{f_p^2 - f_r^2}{f_p \cdot f_r}\right)Q_{full\_load}\right]^2}} \quad (7)$$

Mis calculated by Eq. 7.The LLC circuit must consistently operate above the specified limit frequency denoted as f_p. Iff_s is lower than f_p, ZVS capability becomes non exist. For any value where Q is greater than zero, the M value should exceed the M value that calculated at f_p. To increase efficiency and supplying LD demands, f_s must always be greater than f_p. To meet these conditions, calculating the M value using Eq. 3 and Eq. 7 is essential. Operating within the inductive region guarantees ZVS and ensures high efficiency. When calculating the M value, thorough analysis of the load's electrical characteristics is essential. In this study, the load is LD. Since LD's are current driven devices, they must be carefully analysed and electrical modelling must be carefully done. In this study, LD is modelled as a diode due to its similarities to diodes in terms of electrical parameters, such as having a threshold voltage. It is obvious that when modelling the LD, resistance of the LD must first be calculated by consideringelectrical parameters of the LD. LD parameters are given in Table 1.

Resistance of LD can be calculating by using Eq. 8. Where R_{on} is resistance of LD, V_{op} is operating voltage of LD, V_{th} is is threshold voltage of LD and I_{op} operating voltage of LD. The LD used in this model operates in continuous wave (CW) mode. In addition to obtaining the demanded current value, as mentioned above, one of the most critical issues of LD is the current ripple, and if low current ripple demand can't be satisfied, the LD will overheat and cannot supply the demanded efficiency. Hence, the value of the output filter should be high, and the PFC controller becomes more complex.

$$R_{on} = \frac{(V_{op} - V_{th})}{I_{op}} \quad (8)$$

Controller

Control diagram of PFC LLC LD Driver Circuits shown in Figure 2. Because of the LD's demands, this controller has differences between common PFC controllers. At common PFC controllers, demanded output voltage of the circuit chosen for PFC controller to get demanded output voltage. But in Figure 2 considering with LD's are current driven devices and current ripples are needed minimized, demanded output current I_{outref} is chosen reference signal of PFC controller to supply LD's demands. PI-1 and PI-2 parameters are given at Table 2.

I_{outref} is demanded output current of the circuit and I_{out} is the output current of the circuit. Reference signal of the circuit is chosen output current instead of output voltage to supply

Table 1. Electrical parameters

Threshold Current (A)	1.7 A
Threshold Voltage (V)	24 V
Operating Current (A)	34.04 A
Operating Voltage (V)	30.1 V

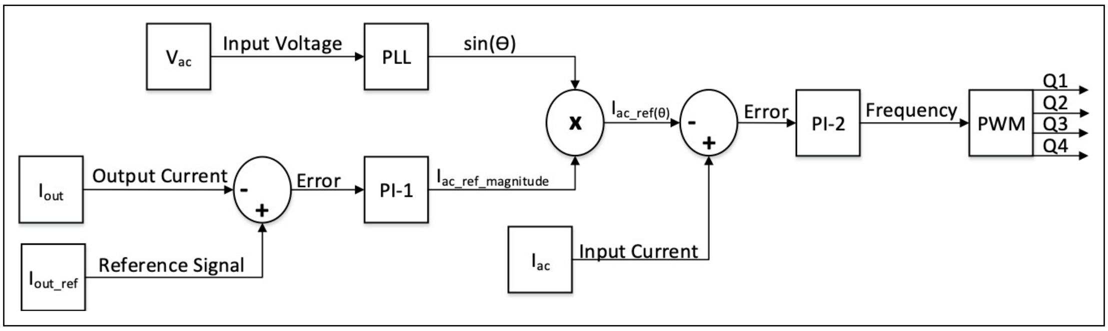

Figure 2. Controller of AC LLC LD driver circuit.

Table 2. PI-1 and PI-2 parameters

PI-1 Parameters	Value	PI-2 Parameters	Value
K_{P1}	0.64706	K_P2	2000
K_{i1}	2.22	K_i2	500000000

LD's demands. PI-1 is utilized to generate $I_{ac\_ref\_magnitude}$ and this way output current is regulated. Differences between I_{outref} and I_{out} is the error signal and this signal is the input parameter of PI-1. $I_{ac\_ref\_magnitude}$ signal is the magnitude of demanded input current. Phase Locked Loop is utilized to get the reference sine signal from input voltage V_{ac}. PLL is generate a reference sin(θ) signal that is the same phase and frequency with V_{ac}. $I_{ac\_ref\_magnitude}$ obtained from PI-1 and used for defining the magnitude of the circuit's input current,sin(θ)is obtained from PLL and used for demanded pure sine shape of the input current. $I_{ac\_ref(\theta)}$ signal is created by multiplying the reference sin(θ)signal and magnitude of demanded input current, $I_{ac\_ref\_magnitude}$. $I_{ac\_ref(\theta)}$ signal is demanded input current. Differences between input current I_{ac} and demanded input current $I_{ac\_ref(\theta)}$ is the input of PI-2. PI-2 is utilized to generate appropriate frequency to the Q1-4 switches gates. Owing to this controller, the desired current value and low current ripples, as demanded by the LD, have been successfully achieved.

Simulation Results

The simulation of the Single-stage PFC LLC LD driver is performed using MATLAB Simulink, validating all the theoretical calculations and diagrams mentioned above. A sample time of 42.553 nano seconds and a stop time of 0.8 seconds were employed, resulting in a comprehensive and detailed analysis. electrical input and output parameters are given at Table 3.

As shown in Table 3 parameters of modelling is performed and LD demands are successfully achieved. As mentioned above, for demanded LLC performance, f_s should not be smaller than f_p *to* operate at inductive region for ensuring ZVS and highly efficiency LLC. As shown in Table 3, 95.44% efficiency has been reached, efficiency value is calculated by using:

$$\eta\% = \frac{P_{out}}{P_{in}}.100 \tag{9}$$

The decrease in efficiency primarily stems from losses incurred in both active and passive components. Passive component losses arise due to inductance, capacitance, and resistance, whereas active component losses are attributed to switching. Notably, switching losses are minimal in this circuit due to the implementation of ZVS in the LLC inverter section. This feature significantly contributes to the circuit's high efficiency. This situation has been achieved by

Table 3. Electrical parameters

Parameters	Descriptions	Parameters	Descriptions
V_{in}	220 V	L_r	26µH
I_{in}	4.88 A	L_m	104µH
P_{in}	1074 W	C_r	392nF
V_{out}	30.1 V	n	6.168
I_{out}	34 A	f_s	24kHz-145kHz
P_{out}	1025 W	f_r	50kHz
Efficiency	0.9544	f_p	22.361kHz
f_{grid}	50 Hz	S1-4	600V, $R_{DS(on)}$=60mΩ
L_{in}	900µH	Q1-4 Switches	650 V, $R_{DS(on)}$=41mΩ
C_{in}	20nF	SR1-2 Switches	60V, $R_{DS(on)}$=2mΩ
L_{out}	60mH	C_{out}	9mF

appropriate determination of the circuit parameters. L_{in} and C_{in} *form* the input filter, while L_{out} and C_{out} constitutes the output filter. Output filter is one of the most critical parts of LD driver because of the LD's low current ripple demand.

The frequency values within an input voltage period, as illustrated in Figure 3, are critical for achieving the required M value. Specifically, at points 0.46-0.47 and 0.48, the input voltage reaches zero, resulting in the minimum frequency. Conversely, at points 0.465 and 0.475, the input voltage peaks, leading to the maximum frequency. This relationship between voltage points and frequency is depicted in both Figure 3 and Table 3. To optimize system performance, it's essential to maintain f_s consistently higher than f_p throughout the entire cycle. This practice safeguards the ZVS feature, ensuring enhanced system performance and efficiency.

As depicted in Figure 4, the LD demands of 30.1 V and 34.04 A have been successfully achieved. Achieving near 1% current ripple, attributed to the output filter and PFC controller, significantly enhances LD performance by mitigating overheating issues and ensuring operational efficiency.

As demonstrated in Figure 5(a), the experimental results reveal the attainment of a nearly pure sine wave input current profile, showcasing the effectiveness of the proposed circuit design in achieving smooth and sinusoidal current waveforms. Furthermore, as illustrated in Figure 5(b), the achieved low current Total Harmonic Distortion (THD) value of 2.53% emphasizes the system's ability to mitigate harmonic distortions, further corroborating its efficient performance. The notable reduction in THD levels signifies the efficacy of the Power Factor Correction (PFC) controller in regulating the input current waveform, thereby ensuring enhanced power quality and reduced electrical noise. These findings highlight the successful implementation of the proposed approach, resulting in minimized input current ripple and the generation of a near-ideal sinusoidal output.

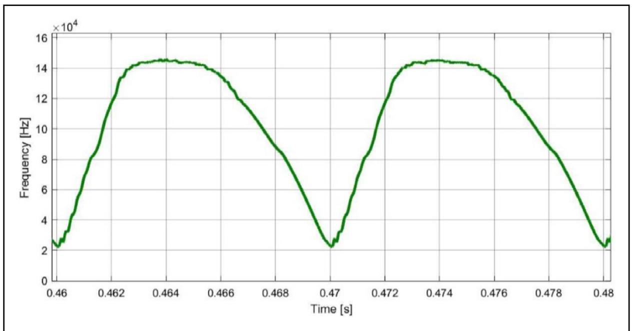

Figure 3. Frequency modulation.

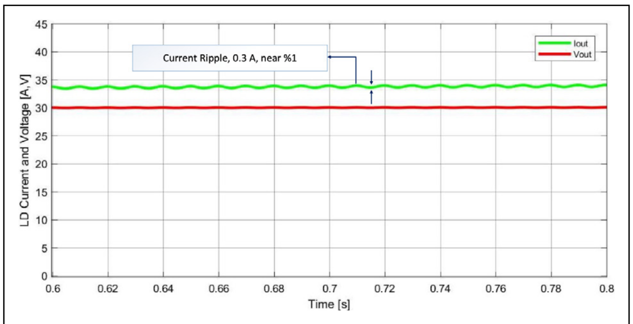

Figure 4. LD current and voltage.

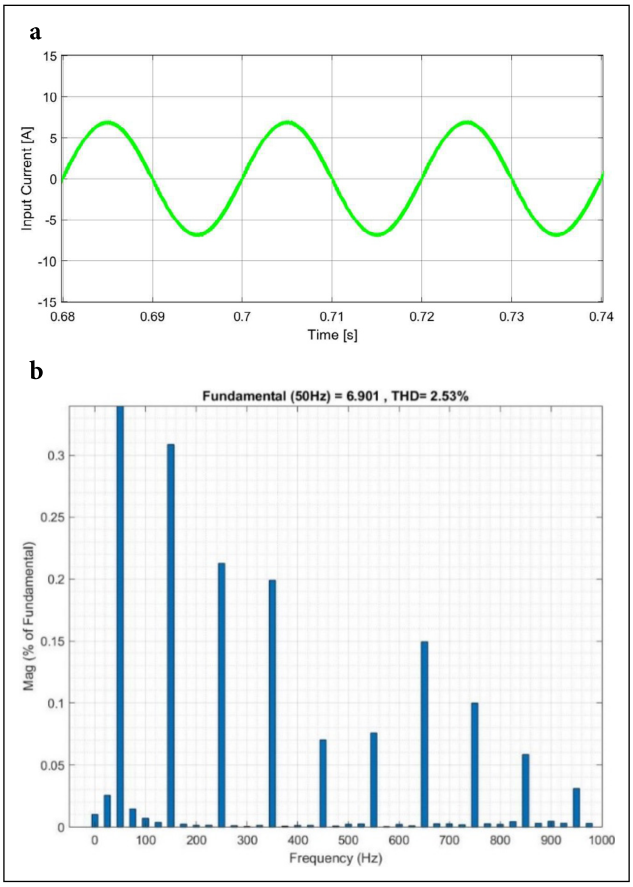

Figure 5. Input current and THD values.

CONCLUSION

In this study, a substantial contribution has been made toward enhancing the efficiency of LD driver systems within LPT technology. Compared to other laser drivers mentioned in the literature, the designed laser driver offers high power and efficiency. In contrast to other grid-connected circuit topologies, it is single-stage and highly efficient as it eliminates the need for an additional switch. However, its controller presents challenges in implementation. The pivotal integration of a robust and efficient LLC resonant converter, incorporating functionalities like PFC, grid integration, and ZVS, stands out. The exceptional achievement of 95.44% efficiency and remarkably low current THD at 2.53% accentuates the effectiveness of the proposed approach. Moreover, meeting precise LD demand specifications, encompassing specific voltage and current requirements with minimal current ripple, further solidifies the applicability of this system within LPT domains. Consequently, this research promises substantial advancements in enhancing LD driver circuit efficiency and performance in the domain of LPT.

Future studies will focus on the suitability and efficiency of AC-DC PFC circuits for LD driving.

ACKNOWLEDGEMENT

This study was supported by Scientific and Technological Research Council of Turkey (TUBITAK) under the Grant Number 121E564. The authors thank to TUBITAK for their supports.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Jin K, Zhou W. Wireless laser power transmission: A review of recent progress. IEEE Trans Power Electron 2019;34:3842–3859.

[2] Triviño A, González-González JM, Aguado JA. Wireless power transfer technologies applied to electric vehicles: A review. Energies 2021;14:1547.

[3] Xie L, Shi Y, Hou YT, Lou A. Wireless power transfer and applications to sensor networks. IEEE Wireless Commun 2013;20:140–145.

[4] Al-Kalbani AI, Yuce MR, Redouté J-M. A Biosafety Comparison Between Capacitive and Inductive Coupling in Biomedical Implants. IEEE Antennas Wireless Propag Lett 2014;13:1168–1171.

[5] Xu W, Wang X, Li W, Lu C. Research on test and evaluation method of laser wireless power transmission system. EURASIP J Adv Signal Process 2022;2022:20.

[6] He T, Zheng G, Wu Q, Huang H, Wan L, Xu K, et al. Analysis and experiment of laser energy distribution of laser wireless power transmission based on a powersphere receiver. Photonics 2023;10:844.

[7] Dai J, Ludois DC. A survey of wireless power transfer and a critical comparison of inductive and capacitive coupling for small gap applications. IEEE Trans Power Electron 2015;30:6017–6029.

[8] Zhu J, Ban Y, Xu R, Mi CC. An NFC-connected coupler using IPT-CPT-combined wireless charging for metal-cover smartphone applications. IEEE Trans Power Electron 2021;36:6323–6338.

[9] Mason R. Feasibility of laser power transmission to a high-altitude unmanned aerial vehicle. RAND Corporation, Santa Monica, CA, USA. Tech Rep TR-898-AF. 2011.

[10] Kawashima N, Takeda K. Laser energy transmission for a wireless energy supply to robots. Proc Symp Automat Robot Construction 2005;373–380.

[11] Lim Y, Choi YW, Ryoo J. Study on laser-powered aerial vehicle: Prolong flying time using 976 nm laser source. Proc Int Conf Inf Commun Technol Converg 2021;1220–1225.

[12] Yigit H, Boynuegri AR. Pulsed laser diode based wireless power transmission application: determination of voltage amplitude, frequency, and duty cycle. IEEE Access 2023;11:54544–54555.

[13] Zhou W, Jin K. Efficiency evaluation of laser diode in different driving modes for wireless power transmission. IEEE Trans Power Electron 2015;30:6237–6244.

[14] Thompson MT, Schlecht MF. High power laser diode driver based on power converter technology. IEEE Trans Power Electron 1997;12:46–52.

[15] Chen F-Z, Song Y-C, Ho F-S. An efficiency improvement driver for master oscillator power amplifier pulsed laser systems. Processes 2022;10:1197.

[16] Sharma A, Panwar CB, Arya R. High power pulsed current Laser Diode driver. 2016 International Conference on Electrical Power and Energy Systems (ICEPES), Bhopal, India. 2016;120–126.

[17] Liu W, Yurek A, Sheng B, Chen Y, Liu Y-F. A single stage 1.65kW AC-DC LLC converter with power factor correction (PFC) for on-board charger (OBC) application. 2020 IEEE Energy Conversion Congress and Exposition (ECCE), Detroit, MI, USA. 2020;4594–4601.

[18] Qiu Y, Liu W, Fang P, Liu Y-F, Sen P-C. A mathematical guideline for designing an AC-DC LLC converter with PFC. 2018 IEEE Applied Power Electronics Conference and Exposition (APEC), San Antonio, TX, USA. 2018;2001–2008.

[19] Zeng J, Zhang G, Yu SS, Zhang B. LLC resonant converter topologies and industrial applications — A review. Chinese J Electr Eng 2020;6:73–84.
[20] Lee J-Y, Jeong Y-S, Han B-M. An isolated DC/DC converter using high-frequency unregulated LLC resonant converter for fuel cell applications. IEEE Trans Ind Electron 2011;58:2926–2934.
[21] Fang Z, Cai T, Duan S, Chen C. Optimal design methodology for LLC resonant converter in battery charging applications based on time-weighted average efficiency. IEEE Trans Power Electron 2015;30:5469–5483.
[22] Chen Y, Yang D, Shao S, Zhang J. Optimal Design of LLC-based Isolated Single-Stage PFC Converter. 2022 IEEE International Power Electronics and Application Conference and Exposition (PEAC), Guangzhou, Guangdong, China. 2022;1649–1654.
[23] Zhou Y, Liu S, Ren J, et al. Design Methodology of LLC Resonant Converters for Single-stage Power Factor Correction Application. J Electr Eng Technol 2021;16:2573–2584.
[24] Luo H, Zang T, Zhao C, Chen S, Zhou Y, Qiu Y, et al. Power boundary controlled single-stage LLC power factor correction converter and ıts optimal parameter design. IEEE Trans Ind Electron 2023;70:12219–12232.
[25] Forouzesh M, Liu Y-F, Sen PC. A line cycle synchronous rectification strategy based on time-domain analysis for single- stage AC–DC LLC converters. IEEE Trans Power Electron 2023;38:5077–5091.

Clean Energy Technol J, Vol. 2, No. 1, pp. 8-13, June, 2024

Clean Energy Technologies Journal
Web page info: https://cetj.yildiz.edu.tr
DOI: 10.14744/cetj.2024.0002

CLEAN ENERGY TECHNOLOGIES JOURNAL

Technical Note

Sustainable energy research at Clean Energy Technologies Institute: An overview

Aysel KANTURK FIGEN[1,2], Gulizar BALCIOGLU[2*]

[1]Department of Chemical Engineering, Yildiz Technical University, Istanbul, Türkiye
[2]Clean Energy Technologies Institute, Yildiz Technical University, Istanbul, Türkiye

ARTICLE INFO

Article history
Received: 21 February 2025
Accepted: 21 February 2025

Key words:
Clean energy; Sustainability, Research; Innovation; Commercialisation.

ABSTRACT

Yildiz Technical University (YTU) Clean Energy Technologies (CET) Institute has started operations in 2022 with the aim to pioneer in advancing clean energy technologies through research and development. Integrating aspects of research, innovation, education and commercialisation it aspires to become leading research centre in Türkiye for innovative energy solutions and support decision makers in developing key energy policies for a sustainable society. Bringing together pioneering research leaders, the Institute has organised in eight research groups that correspond to different thematic areas in the energy sector. Being designed to train future energy and sustainability leaders with the appropriate skills and knowledge, two postgraduate degree programmes (at Master and PhD levels) in the field of Advanced Energy Technologies are offered to graduates from a broad range of disciplines and have a strong interest in clean energy technologies. In the long term, the Institute hopes to address regional and global challenges in the clean energy technologies and develop sustainable solutions in the sector with the help of a strong connection between scientists, industrial and research partners and policy makers.

Cite this article as: Kanturk Figen A, Balcioglu G. Sustainable energy research at Clean Energy Technologies Institute: An overview. Clean Energy Technol 2024;2(1):8-13.

INTRODUCTION

Energy is at the corner store of modern society, linking to social welfare and economic growth. However, many primary sources are not sustainable [1]. The existing fuel mix contributes to numerous environmental issues, such as global climate change, acid rain, freshwater consumption, air pollution, and radioactive waste, all of which also threading the social welfare and socio-economic activities [2-3]. To be sustainable, today's energy industry requires not only a shift from carbon-intensive systems to less environmentally destructive ones based on renewable sources and greener practices but also corresponding changes

Highlights

- Clean Energy Technologies Institute aims to be a leading energy and sustainability-focused research centre integrating aspects of research, innovation, education and commercialisation.
- The Institute provides a high-quality multidisciplinary research environment to tackle global and regional challenges in clean energy technologies through research and teaching,
- Subject areas covered a wide array of topics such as energy storage technologies, energy logistics, policies and strategies, hydrogen and alternative fuel technologies, economic, social impact and sustainability.

***Corresponding author.**
*E-mail address: gulizar.balcioglu@yildiz.edu.tr

Published by Yıldız Technical University, İstanbul, Türkiye

in governance, institutional frameworks, legal regulations, public attitudes, and consumption habits [4-5].

However, the question how to replace conventional technologies by renewables brings other important questions that need to be answered: What are alternative energy technologies to fossil resources? What does the future hold for them? What do they mean in terms environmental, economic, and social sustainability? Which technologies and systems are more efficient to achieve low emissions and environmental benefits while ensuring economic growth and social welfare? How these technologies be improved through new developments in related areas, such as material science, chemistry, and physics? [5-6].

CLEAN ENERGY TECHNOLOGIES INSTITUTE

Since its founding in 2022, Yildiz Technical University (YTU) Clean Energy Technologies (CET) Institute [7] has made answering such questions its business as a multi-disciplinary energy ecosystem focusing on its activity areas including "Research, Innovation, Education, Commercialization and Service" (Fig.1a). Being located at the centre of Istanbul, CET Institute is a world class research centre established with the aim to pioneer in advancing clean energy technologies through research and development of state-of-the art technologies and to translate results of research activities to actionable knowledge that can support public policies and research innovation and commercialization studies and thereby increase CET's impact on economy and the society (Fig.1b). It will also help provide insights to policymakers in the implementation of the European Green Deal and develop strategies for the achievement of net zero target of Türkiye by 2053 [8].

Bringing together a multidisciplinary group of researchers, educators and industrial partners, the CET Institute is uniquely placed to provide technical, social and cultural solutions based on clean energy technologies to contribute sustainable energy, environment and industry through different type of projects sponsored by YTU and other national and international organisations. These solutions will contribute to decarbonization and reduction of global warming while training researchers and students to be leaders in renewable energy-focused research and provide innovative solutions in topics where science and technology matters.

The vision of the YTU CET Institute is to be one of the World's Excellence Centres in the field of clean energy technologies. In line with the Institute's vision, the missions are;

- To create a world-class research cluster,
- To primarily consider research, innovation and technology development,
- To work with local partners for sustainable development of Türkiye, and
- To conduct cutting-edge research for current problems and future technologies and their development.

In this purpose the objectives that leads to this mission and vision can be defined as;

- To excel in research, development and innovation,
- To play a key role in technology development and transfer,
- To develop partnerships with industry, government agencies, and other institutions,
- To advance knowledge,
- To educate and train people, students, researchers, scientists etc.,
- To serve local community for solving their problems, and
- To organize local and international events to disseminate new developments.

Based at the YTU Davutpasa Campus, the CET Institute offers a unique multidisciplinary research environment through its taught and research programmes in Advanced

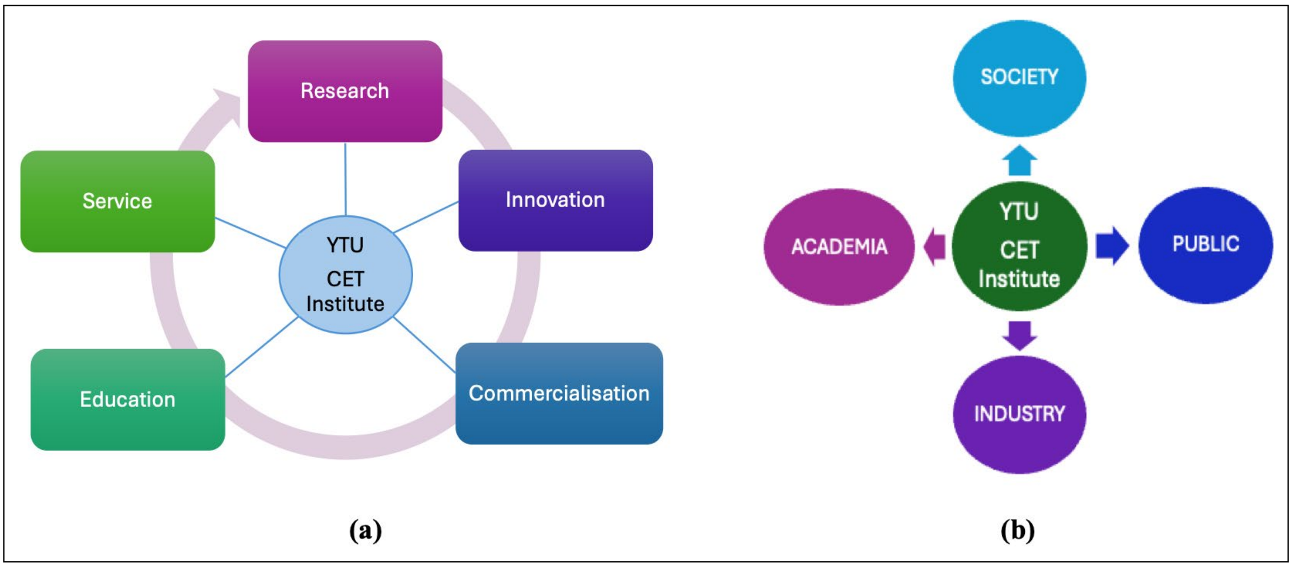

Figure 1. The CET Institute's activities **(a)** and stakeholders **(b).**

Energy Technologies not only to train highly employable graduates with knowledge and skills in their chosen field but also to meet the increasing demand for skilled workers and leaders needed to deliver the clean energy transition. Master and PhD programmes are respectively run over 24 months and 48 months (at least), with two semesters of taught courses followed by a research project leading to a research thesis. Applicants with a background in energy issues or a strong interest in topics that falls within Institute's research themes, can develop their research skills and acquire in-depth technical knowledge balanced with practical experience at state-of-the art research facilities and laboratories including Hydrogen Research Centre, and Battery Research and Testing Centre, Energy Efficiency Centre and Clean Combustion Research Centre. To provide students with a comprehensive understanding of what clean energy technologies, these programmes cover a wide array of topics. Though the programme is grounded in engineering, students can benefit from the programme's multidiscipline design, with courses considering the environmental, societal, economic and policy aspects of the energy industry and thereby giving new career opportunities in the broad field of clean energy technologies. The professional development of researchers is also supported by workshops, publications and internal and external seminars. Promoting open-access publication, Clean Energy Technologies Journal hosted by YTU provides an opportunity to disseminate project's research outputs and CET's impact to a wider community after a thorough peer-review process. In line with the mission to translate knowledge into added value, YTU Yildiz Technopark also supports researchers and academics to commercialise the outcomes of research on subjects such as patents, license agreements, technology transfer, helping explore start-up business idea and providing funding opportunities.

Today, the CET Institute with the core scientific staff and increasing number of post-graduate students and researchers every year investigates the regional and global challenges in clean energy technologies ranging from improving efficiency of different technologies to understanding their sustainability implications. CETs scientists represent every branch of energy science and technology as well as other fields where interdisciplinary research is necessary to put these technolo-

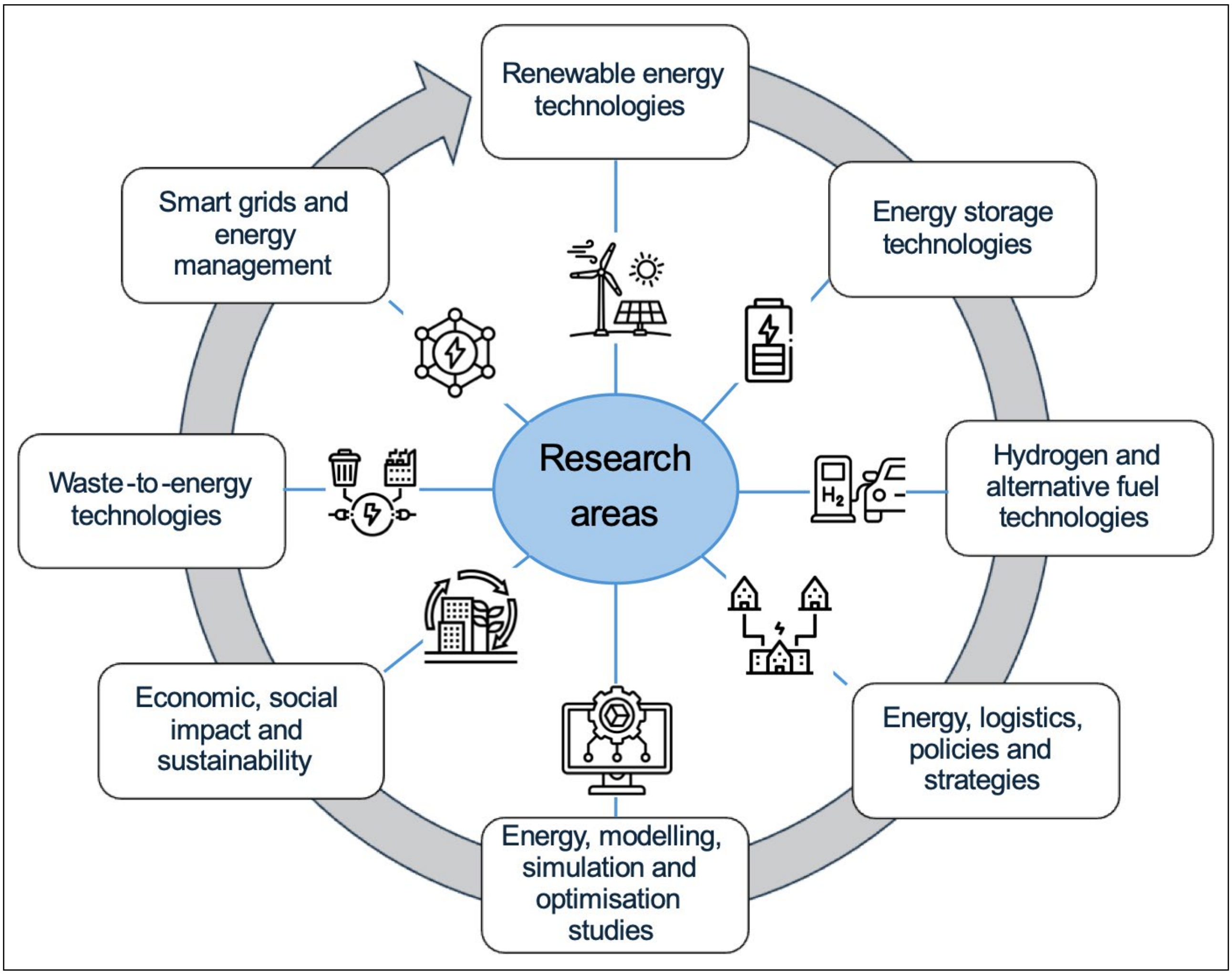

Figure 2. Main research areas in the CET Institute.

gies into action, such as economy and policy research. Prof. Dr. Aysel Kanturk Figen, who is also a board member of the National Hydrogen Association, is assigned as the director of the CET Institute. Many other scientists and collaborators at universities and research centres around the world also take part in the advisory board of the CET Institute, including National Hydrogen Association's chair Prof. Dr. Ibrahim Dincer from Ontario Tech University / Yildiz Technical University, Prof. Dr. Neven Duić from University of Zagreb, Prof. Dr. Feridun Hamdullahpur from University of Waterloo, Prof. Dr. Bruce Logan from Penn State University, Prof. Dr. Mihri Özkan from University of California-Riverside, Prof. Dr. Seeram Ramakrishna from National University of Singapore, Prof. Dr. S. Ravi P. Silva from University of Surrey, Prof. Dr. Benjamin K. Sovacool from University of Sussex, Prof. Dr. Peter Strasser from Technische Universität Berlin, Olcay Unver from Arizona State University and Zafer Ure from Phase Change Material Products Limited.

MAIN RESEARCH AREAS

The centre's research is organised around eight scientific divisions, each representing critical components of energy research, though not limited to them (Fig. 2). Within this scope, smart grid and energy management, waste-to-energy, energy storage technologies, energy logistics, policies and strategies, hydrogen and alternative fuel technologies, modelling, simulation and optimization of energy systems, renewable energy technologies, economic, social impact and sustainability are the main topics that researchers at CET Institute focus on.

A short description of each research group and areas of work are provided in the following sub-sections.

The Smart Grid and Energy Management Research Group

Smart Grid and Energy Management Research Group aims to provide innovative solutions to the complex problems of electric power system operation from different stakeholders' perspectives. The mentioned innovative solutions include artificial intelligence and optimization-based decision-making mechanisms as well as planning tools for production, transmission, distribution and consumption centres together with technoeconomic players. Last but not the least, multi-energy solutions including the simultaneous operation of different energy types' infrastructures are also within the scope of this research group.

The Waste-to-Energy Research Group

The Waste-to-Energy Research Group is dedicated to developing biological, chemical, and bio-electrochemical bioenergy production technologies from various waste streams to offer low-cost and environmentally sustainable solutions for waste management, recycling, and recovery.

The research group has been centred on academic research projects carried out with different industries to include wastes in a circular economy model and observe the life cycle assessment of processes. It focuses on building up new technologies for sustainable waste management, environmentally friendly energy production and storage.

The Energy Storage Technologies Research Group

The Energy Storage Technologies Research Group aims to cover all important aspects of energy storage technologies, in particular novel energy storage technologies. The Energy Storage working group is focusing on the theory and applications of mechanical, electrochemical, chemical, electrical, and thermal energy storage systems. In addition, different aspects of energy storage technologies in electrified transportation, off-grid systems, portable electronic system, and grid-scale electrical storage are considered. Demand and management of intermittency in large-scale low-carbon power generation with energy storage systems are other topics to be considered within the work carried out by researchers in this group. Another indispensable research subject in the group is Vehicle-to-grid, energy storage integrated with buildings, and multi-purpose and hybrid storage systems. Furthermore, life cycle costs, life cycle assessment, the safety of energy storage systems and their economic, policy, and regulatory aspects, and market introduction concepts will be studied.

The Energy Logistics, Policies and Strategies Research Group

The Energy Logistics, Policies and Strategies Research Group (ELPS) aims to analyze and discuss the related policies and strategies of energy based on clean and renewable energy alternatives. Additionally, the group aims to analyse future energy perspectives of countries to obtain a road map for energy management. The ELPS group also concentrates on design the most ideal logistics strategy for energy management. The group also investigates how to determine the best network design for logistic with respect to right locations, methods, tools and transport strategies between destinations for all of the energy types.

The Hydrogen and Alternative Fuel Technologies Research Group

The Hydrogen and Alternative Fuel Technologies Research Group pioneers research and development in energy strategy solutions based on hydrogen and alternative fuels. The formulation of solutions to the CO2-free energy systems links to the hydrogen-related industries necessitating to address the challenges in technological trends and creating alternative pathways for realization. We have been focused on different aspects of key research areas, propose new projects in cooperation, and launch new activities.

Especially, balancing the electrical power consumption has a significant effect in the perspective of investments and carbon free energy production as it has peaks and valleys due to its own characteristics. In another word the storage of the excessive energy due to the intermittent energy production of renewable energy sources and using this energy in the peak times where the load demand is generally supplied by the fossil fuels provides new opportunities not only for decreasing environmental burdens but also for reducing the investment cost of energy plants. Hydrogen energy with its high energy density and potability is a prominent key solution technology for the near future in this area. Hydrogen generation, storage, transportation, certification, and injecting hydrogen to natural gas etc. are the research topics studied by the experts of this research group. R&D studies for green hydrogen production, hydrogen vehicles, fuel cells and the auxiliary equipment for hydrogen storage and technologies are the priorities of this research group.

The Modelling, Simulation and Optimization of Energy Systems Research Group

Modelling, Simulation and Optimization of Energy Systems Research Group focuses on the classical and advanced Modelling, Simulation and Optimization Technics (theoretical, statistical, and Artificial Neural Network (ANN) models) to develop better Energy Systems by using Art and Science as Tools.

The group focuses on cross disciplinary research in energy system modelling, simulation and optimization to improve understanding of the energy processes, to optimize process and operating conditions, to design a control strategy for the energy process, to simulate a model to optimize system performance or to make predictions about a real system, and to study the characteristics of a real-life or fictional system by manipulating variables that cannot be controlled in a real system.

The Renewable Energy Technologies Research Group

The Renewable Energy Technologies Research Group (RETRG) contributes to the research and development of new renewable energy technologies that are cost-effective, stable, sustainable and environmentally friendly, as well as improving existing renewable technologies in innovative ways, by developing new materials and concepts for reducing carbon footprint. In addition to energy production with renewable technologies, energy saving is also within the area of interest. We envision new scientific projects based on the energy systems of the sustainable future. On the other hand, the group participates in social responsibility activities/projects to raise awareness about the benefits of energy saving, understanding of global warming and its serious consequences.

The Economic, Social Impact and Sustainability Research Group

The Economic, Social Impact and Sustainability Research Group measures the economic impacts of both developed and planned clean energy technologies and evaluate their possible societal impacts. It also examines the relation between those technologies and the sustainability goals, especially the United Nations Sustainability Goals. In addition, it helps to develop economic and social impact analyses of projects that are led by other research groups.

CONCLUSION

With all the mentioned specialties, young and dynamic CET Institute serves as a research ecosystem which consist of research groups including interdisciplinary national and international experts, strong industrial relationships, and solution partnerships. The Institute aims to finance its own R&D investments with the help of stakeholder system, sustainable solution partnerships for sustainable energy. For this purpose, the institute has a mission to convert technology to an economic outcome with the rule of science to technology and technology to product. The widely open doors for national and international project partnerships and considering socio-cultural part of the technology is set apart the CET Institute and transform it to a next generation R&D ecosystem.

This article is prepared as part of the special issue on "Clean Energy Technologies Institute". In the following section of this journal, readers can find out more about core three research facilities at the CET Institute (Energy Efficiency Centre, Hydrogen Research Centre and Battery Testing and Research Centre), including their areas of research, current projects and recent publications.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] International Energy Agency. World Energy Outlook 2024 Paris: IEA; 2024 Available at: https://www.iea.org/reports/world-energy-outlook-2024 Accessed Feb 24, 2025.

[2] Martins F, Felgueiras C, Smitkova M, Caetano N. Analysis of fossil fuel energy consumption and environmental impacts in European countries. Energies 2019;12:964. [CrossRef]

[3] Elshkaki A. The implications of material and energy efficiencies for the climate change mitigation potential of global energy transition scenarios. Energy 2023;267:126596. [CrossRef]

[4] Asmelash E, Prakash G, Gorini R, Gielen D. Role of IRENA for global transition to 100% renewable energy. In: Uyar T, editor. Accelerating the transition to a 100% renewable energy era. Cham: Springer; 2020. p. 17–39. (Lecture Notes in Energy; vol. 74). [CrossRef]

[5] Khan I, Hou F, Zakari A, Tawiah VK. The dynamic links among energy transitions, energy consumption, and sustainable economic growth: A novel framework for IEA countries. Energy 2021;222:119935. [CrossRef]

[6] Araújo OQF, de Medeiros JL. How is the transition away from fossil fuels doing, and how will the low-carbon future unfold? Clean Techn Environ Policy 2021;23:1385–1388. [CrossRef]

[7] Clean Energy Technologies Institute. Clean Energy Technologies Institute, 2025. Available at: https://tet.yildiz.edu.tr/ Accessed Feb 24, 2025.

[8] Net Zero Türkiye. The 2053 net-zero target and Türkiye's long-term climate change strategy, 2025. Available from: https://netsifirturkiye.org/en/the-2053-net-zero-target-and-turkiyes-long-term-climate-change-strategy/ Accessed Feb 24, 2025.