# THEORETICAL AND APPLIED RESEARCH IN ENGINEERING

Editor

Prof. Dr. M. Sait CENGİZ

# THEORETICAL AND APPLIED RESEARCH IN ENGINEERING

**Editor**
**Prof. Dr. M. Sait CENGİZ**

*Theoretical And Applied Research In Engineering*
*Editor: Prof. Dr. M. Sait CENGİZ*

**Editor in chief:** Berkan Balpetek
**Cover and Page Design:** Duvar Design
**Printing :** October -2025
**Publisher Certificate No:** 49837
**ISBN:** 978-625-8734-11-9


853 Sokak No:13 P.10 Kemeraltı-Konak/İzmir
Tel: 0 232 484 88 68
*www.duvaryayinlari.com*
*duvarkitabevi@gmail.com*

## TABLE OF CONTENTS

# Chapter 1

# Perturb And Observe Control-Based MPPT Algorithm for Photovoltaic System with Sepic Converter Under Changing Environmental Conditions

**Evren ISEN[1], Burcin OZKAYA[2]**

## 1. INTRODUCTION

Increasing global energy demand, the risk of fossil fuel depletion, and environmental problems are increasingly driving the importance of renewable energy sources. Among these sources, solar energy is one of the most essential alternatives due to its clean, inexhaustible, and environmentally friendly nature [1-3]. Photovoltaic (PV) systems, which generate electricity directly from solar energy, are widely used in both small-scale off-grid applications [4-6], and grid-connected power plants [7-9].

The electrical behavior of PV cells is described by current-voltage (I–V) and power-voltage (P–V) characteristic curves. The I–V curve shows the relationship between the cell's short-circuit current ($I_{sc}$) and open-circuit voltage ($V_{oc}$), while the P–V curve reveals the power that can be generated at different operating points. These curves are nonlinear and constantly change with irradiance and temperature [2, 9]. For example, when irradiance increases, the short-circuit current increases, while increasing temperature generally decreases the open-circuit voltage. Under these conditions, only one point on each I–V or P–V curve provides the highest power output. This point is known as the Maximum Power Point (MPP), and it is the point at which the PV cells operate most effectively. However, one of the main problems with PV systems is that this MPP isn't always the same [10, 11]. Conditions like changes in solar irradiance, temperature, cloud cover, or partial shading can change the MPP all the time. If the system works at a point other than the MPP, a lot of the potential energy production is lost, and the system often makes less electricity than it could. This situation makes energy use less efficient from a technical point of view and makes it take longer to get back the money spent on investments from an economic point of view. These

[1] Assoc. Prof. Dr., Bandırma Onyedi Eylül University, Faculty of Engineering and Natural Sciences, Department of Electrical Engineering. eisen@bandirma.edu.tr, ORCID No: 0000-0002-3107-9255.
[2] Assoc. Prof. Dr., Bandırma Onyedi Eylül University, Faculty of Engineering and Natural Sciences, Department of Electrical Engineering, bozkaya@bandirma.edu.tr, ORCID No: 0000-0002-9858-3982.

losses can have serious economic consequences, especially in large-scale PV plants. Therefore, the implementation of Maximum Power Point Tracking (MPPT) methods has become essential in PV systems. MPPT algorithms continuously monitor the operating points of PV panels, instantly adjusting operating conditions and ensuring that the system operates at the MPP at all times. This increases energy efficiency, reduces unit energy costs, and ensures stable system operation [3]. One of the best ways to implement MPPT algorithms is to use a DC-DC converter between the PV source and the load. The presence of a controller effectively changes the resistance seen by the panel, thus allowing the panel to operate closer to the MPP [1].

Various methods have been developed and applied in various studies by many researchers in the literature. Among these methods, Perturb & Observe (P&O) [12-22], Incremental Conductance (INC) [14], Open Circuit Voltage (OCV) [23], and Short Circuit Current (SCC) [24] are among the most widely used. Among these methods, P&O is the most frequently studied method by researchers, and its various versions have been developed. Isen and Sengul presented a comparative study using P&O, INC, OCV, and SCC methods using boost converter. These methods were operated under varying environmental conditions [12]. Ahmed and Salam proposed an improved P&O method, where a dynamic perturbation step-size was used in the proposed method to reduce the oscillation. To demonstrate the efficacy of the proposed method, it was compared to the conventional and adaptive P&O method [13]. Devi et al. introduced a modified P&O method with directional step size to minimize steady state oscillation and avoid losing the tracking direction of the conventional P&O based MPPT for PV systems [15]. Alik and Jusoh presented a modified MPPT method for PV systems utilizing an enhanced P&O with a checking algorithm. This checking algorithm compares all peak points to determine the global maximum power before the improved P&O algorithm determines the voltage at MPP to calculate the boost converter duty cycle [16]. Abdel-Salam et al. proposed an improved P&O method, which were tested under step and slope changes of irradiation conditions. The proposed method outperformed conventional and modified P&O methods in tracking speed, accuracy, steady-state efficiency, and dynamic efficiency [17]. Majstorović et al. presented a comparative study using P&O and INC methods using sepic converter [18]. Singh et al. presented a P&O based MPPT method using boost converter in PV systems. The method was operated under changing solar irradiation levels [19]. Chellakhi et al. proposed an improved adaptable step-size P&O MPPT method for standalone PV systems using buck converter. The proposed method was tested under changing solar irradiation and temperature, and was compared to different MPPT methods [20]. Kumar and

Bindal used the classic P&O method with a buck-boost converter for PV systems. To determine the efficacy of MPPT, the model was simulated and observed under partial shading conditions [21]. Jabbar et al. proposed a modified P&O method to achieve optimal MPPT in a variety of weather scenarios. A more rapid tracking convergence was achieved using a novel approach to regulate the duty-cycle perturbation step size [22].

In this study, the performance of a photovoltaic system consisting of a SEPIC converter, one of the non-isolated dc-dc converters, and a PV panel is investigated under different irradiance values. 30 PV panels were used in the 6.4 kW system. The simulation study performed at irradiance values of 1000 W/m$^2$, 800 W/m$^2$, and 400 W/m$^2$ under a constant temperature of 25°C, 6.386 W, 5.152 W, and 2.587 W of power are obtained from the panel, respectively. The system's transient response is also successful, and the SEPIC converter extracted the desired power from the panels under the tested operating conditions. The results show that the SEPIC converter is suitable for photovoltaic systems.

## 2. PHOTOVOLTAIC PANEL AND MAXIMUM POWER POINT TRACKING ALGORITHM

PV panels, the primary power source of photovoltaic systems, are crucial during the design phase to enable system analysis through modeling. Therefore, single-diode, dual-diode, and triple-diode models of PV panels are presented in the literature [25]. A single-diode circuit model is also used in this study. Figure 1 shows the single-diode circuit model of a photovoltaic panel [26]. This model includes a current source, a diode, and a resistor. Multiple diodes are shown connected in series and parallel. $N_s$ and $N_p$ represent the number of series diodes and parallel branches, respectively. The values of the series and parallel resistors at the output also vary depending on these numbers. Assuming that both values are 1, the resulting circuit represents a PV panel model.

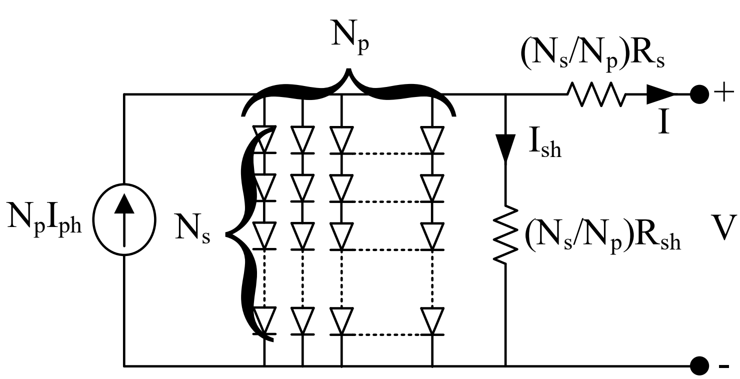



**Figure 1.** PV panel single diode model

When the circuit equation is written based on Kirchhoff's current law in the single diode PV panel model shown in Figure 1, equation (1) is obtained. This equation calculates the output current of a PV panel.

$$I = N_p I_{ph} - N_p I_0 \left[ \exp\left( \frac{\frac{V}{N_s} + \frac{IR_s}{N_p}}{nV_t} \right) - 1 \right] - I_{sh} \tag{1}$$

The first part of the equation (1) represents the current generated by irradiation. The second part represents the current of $N_p$ parallel branches formed by $N_s$ diodes, while the last part represents the current of the $R_{sh}$ resistance at the output. Relevant studies in the literature can provide detailed information regarding the calculations of the parameters and unknown expressions [26].

Maximum power point tracking algorithms are used in the control structure of converters to regulate the power output of the PV panel [27]. The P&O algorithm works by constantly monitoring the voltage and power changes. It tracks the variations in voltage and power at specific intervals. Based on these changes, the duty cycle of the switching element is adjusted. Pseudocode for the P&O algorithm is shown in Algorithm-1. As shown in the algorithm, current and voltage measurements are taken first. Here, k and k-1 denote the current and previous measurements. First, the power value is calculated by multiplying the current and voltage, then the difference between the voltage and power at the two measurement points is calculated. From this point onward, the algorithm operates based on the power and voltage difference values. Firstly, the power difference is checked to see whether it is zero. If the difference is zero, the system operates at the desired power value, and no change is made in switching. Operation is continued with the current panel voltage. If the power difference is different from zero, it is checked whether the increase of this difference is greater or less than zero. In the next step, the voltage difference is checked for both cases. Thus, four different situations arise, and as shown in the figure, the panel output voltage is decreased and increased in each case. This cycle runs continuously and tries to ensure that the panel operates closest to the point where it can produce maximum.

Figure 2 shows the voltage depending on the panel output power. As can be seen, the change in voltage and power is positive in the first region, meaning the power increases as the voltage rises. This is the region where the power increases. When the power reaches its maximum point, region 2 begins. The maximum point is reached in this interval, and the power oscillates. When the algorithm adjusts the reference voltage, it causes a transition to the right and left of the maximum point. The system operates around this point rather than at a single point. The last region is the third one. Here, a decrease in power occurs as the voltage increases. If the system operates in this region, the voltage must be reduced to return to the second region.

**Algorithm-1:** Pseudocode of the P&O algorithm

**Inputs**: $V(k)$ and $I(k)$
**Output**: $V_{ref}$

```
1.   Calculate ΔV(k) = V(k) - V(k-1)
2.   Calculate P(k) = V(k) * I(k)
3.   Calculate ΔP(k) = P(k) - P(k-1)
4.   if ΔP(k) == 0 then
5.     Go to line-21
6.   else
7.     if ΔP(k) > 0 then
8.       if ΔV(k) > 0 then
9.         Decrease Vref
10.      else
11.        Increase Vref
12.      endif
13.    else
14.      if ΔV(k) > 0 then
15.        Increase Vref
16.      else
17.        Decrease Vref
18.      endif
19.    endif
20.  endif
21.  Vref(k) = Vref(k-1)
```

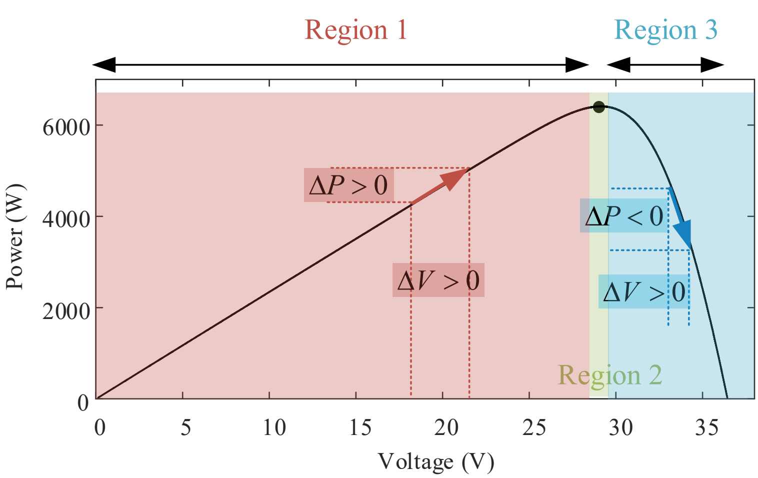



**Figure 2.** Voltage-dependent power variation

Table 1 illustrates the operating principle and zones in the power change graph shown in Figure 2. This table outlines the operating zones based on voltage and power value changes and the actions to be taken in the next cycle according to the operating zone. If the ΔP/ΔV ratio is positive, the panel output voltage should be increased; if it is negative, the panel voltage should be decreased.

**Table 1.** P&O working principle

| ΔV | ΔP | ΔP/ΔV | Region | Next ΔV |
|---|---|---|---|---|
| + | + | + | 1 | + |
| + | - | - | 3 | - |
| - | + | - | 2 | - |
| - | - | + | 2 | + |

## 3. SEPIC CONVERTER

The SEPIC converter is one in which the output voltage decreases, increases, or remains the same according to the input voltage, depending on the conversion ratio. This feature provides an advantage in terms of use at the output of the PV panel, whose output voltage varies according to weather conditions. It is also a preferred converter in applications requiring low input current fluctuations [28]. The polarity of the output voltage and the polarity of the input voltage are the same. Figure 3 shows the circuit diagram of the SEPIC converter. Unlike the buck converter, boost converter, and buck-boost converter without a transformer, two inductances and two capacitors are used in this converter.

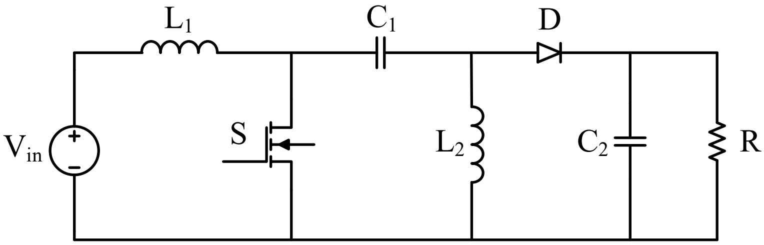



**Figure 3.** SEPIC converter circuit

Figure 4 shows the conduction mode of the converter. In this mode, the switch is in conduction, and the diode is cut off. Energy is stored in the inductance $L_1$ via the input source in this interval. While the energy stored in the capacitor $C_s$ in the previous mode is transferred to the inductance $L_2$, the load at the output is fed from the capacitor $C_2$, which is also stored in the previous operation interval.

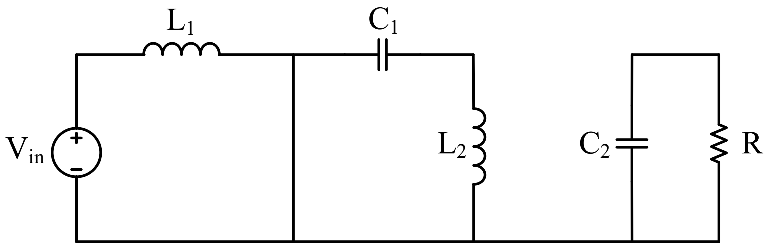



**Figure 4.** Conduction mode

The second operating interval, where the switching element is in cutoff mode and the diode is in conduction, is shown in Figure 5. In this interval, the energy stored in inductance $L_1$ is transferred to capacitor $C_1$, while the energy stored in inductance $L_2$ in the previous interval is transferred to the output.

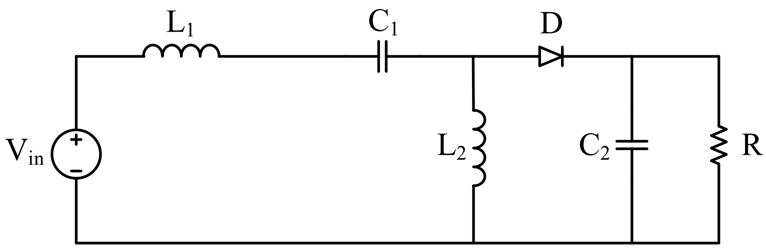



**Figure 5.** Cutoff mode

Equation (2) gives the mathematical expression of the converter's output voltage with two operating ranges in terms of input voltage and conversion ratio. According to this equation, when the conversion ratio is less than 50%, the SEPIC circuit works as a step-down converter, and when this ratio is above 50%, it works as a step-up converter.

$$V_0 = \frac{DV_{in}}{(1-D)} \tag{2}$$

In the equation, $V_{in}$, $V_0$, and $D$ define the input voltage, output voltage, and duty cycle, respectively.

## 4. SIMULATION RESULTS

The simulation circuit created in the Simulink/MATLAB environment within the scope of the study is given in Figure 6. The PV panel array is located at the system input. There are a total of 30 panels in this array. This array consists of 3 parallel arms with 10 series-connected panels in each arm. The electrical parameters of the panels used are given in Table 2. When the total panel array is considered, the system has a power of 6.387 W.

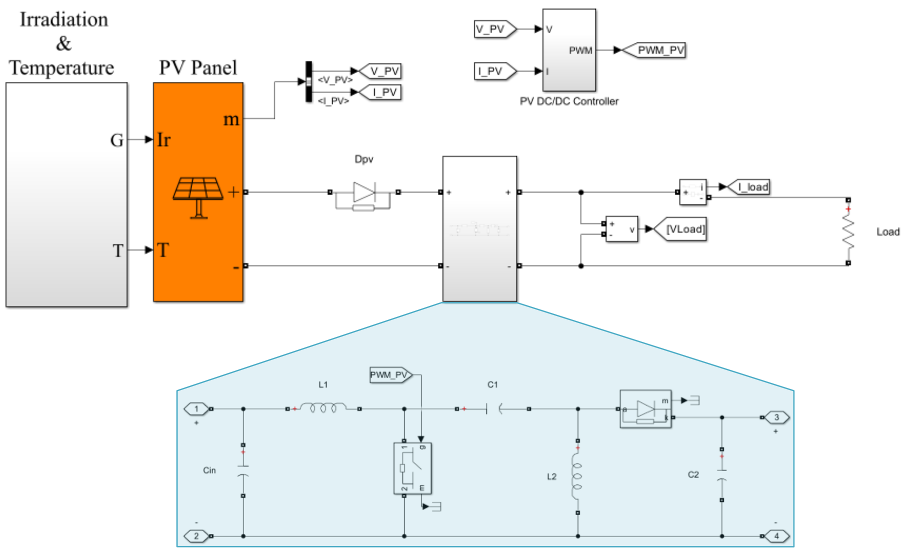



**Figure 6.** Simulation circuit

Table 2 shows the parameters of the PV panel used. These values are obtained under standard test conditions (STC) of 1000 W/m2 radiation and 25°C temperature. The panel consists of a combination of 60 cells. While the open circuit voltage is 36.3 V when no current is drawn from the panel, the panel voltage drops to 29 V during operation at the maximum power point. In a short circuit, 7.84 A can be drawn from the panel, while the panel gives 7.35 A current at the maximum power point. According to these data, a panel can produce 213.15 W of power in STC. These values vary at different irradiation and temperature values.

**Table 2.** PV panel parameters

| Parameter | Value |
| --- | --- |
| $N_{cell}$ | 60 |
| $P_{max}$ | 213.15 W |
| $V_{oc}$ | 36.3 V |
| $I_{sc}$ | 7.84 A |
| $V_{mp}$ | 29 V |
| $I_{mp}$ | 7.35 A |

In the simulation environment, a constant temperature of 25°C and irradiance values of 400W/m$^2$, 800W/m$^2$, and 1000W/m$^2$ were used. To control the power values obtained during the operation of the system, the voltage-dependent power change curves of the panel under these operating conditions were first obtained. Figure 7 shows the maximum power values at 400W/m$^2$, 800W/m$^2$, and 1000W/m$^2$ irradiance as 2.587 W, 5.153 W, and 6.387 W, respectively. These curves will be used to verify the simulation results.

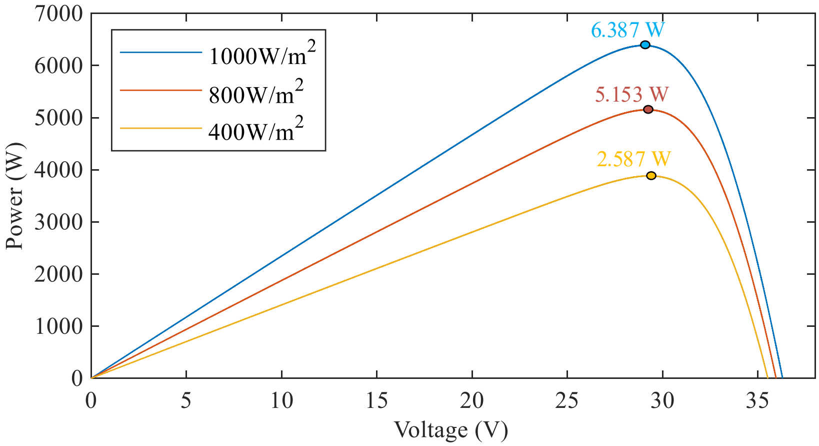



**Figure 7.** PV panel output power curves at constant 25°C and different irradiances

The irradiation variation used to test the system's performance in the simulation environment is given in Figure 8. After applying 800 W/m$^2$ irradiation for the first 0.5 s, 1000 W/m$^2$ irradiation is applied for 1-2 seconds, and 400 W/m$^2$ irradiation is applied for 2.5-3 seconds. The transition between constant irradiation values is provided by a linear change. With this irradiation variation, the response of the system in the case of increasing and decreasing irradiation can be analyzed.

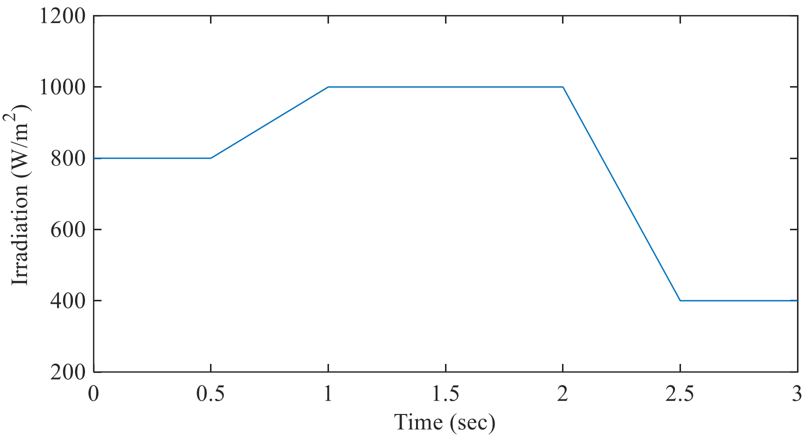


**Figure 8.** Irradiation in the simulation

As seen in Figure 6, the SEPIC converter is located after the PV panels in the system. Table 3 gives the values of the circuit elements used in the converter.

**Table 3.** SEPIC converter parameters

| Component | Value |
|---|---|
| $C_{in}$ | 10 μF |
| $C_1$ | 20 μF |
| $C_2$ | 470 μF |
| $L_1$ | 1.2 mH |
| $L_2$ | 300 μH |
| $R_{load}$ | 100 Ω |
| *Switching frequency* | 15 kHz |

The variation of the load power and the power drawn from the PV panel under the determined temperature and irradiance values is shown in Figure 9. After the transient at the start of the system, the panel output power reached 5.152 W. At the end of 1 second, the irradiance increased from 800W/m$^2$ to 1000W/m$^2$, and the power value reached 6.386 W. When the irradiance value decreased from 1000W/m$^2$ to 400W/m$^2$, the power value decreased to 2.587 W. Considering the maximum power values in Figure 7, the accuracy of the results obtained can be understood. While the system can reach the desired power values in the steady state, it also performs well in transient conditions. When the output power is analyzed, it is seen that a lower power is obtained compared to the input power due to losses. When analyzed for the same time intervals with the PV panel power, the output power reached 4.767 W, 5.916 W, and 2.377 W, respectively. PV panel and output power values are given in

Table **4**.

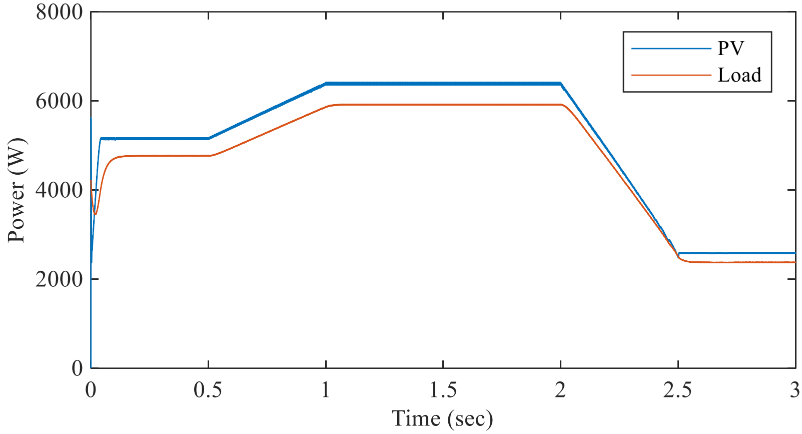



**Figure 9.** PV panel power

**Table 4.** Power values of the PV panel and output

| Irradiation ($W/m^2$) | PV Power (W) | Output Power (W) | ΔP (W) | ΔP (%) |
|---|---|---|---|---|
| 400 | 2.587 | 2.377 | 210 | 8.11 |
| 800 | 5.152 | 4.767 | 385 | 7.47 |
| 1000 | 6.386 | 5.916 | 470 | 7.36 |

When

Table **4** is analyzed, it is observed that the generated power and output power increase with the increase in irradiance. The power difference represents the losses in the SEPIC converter. With the increased generated power, the power losses increase, but a decrease occurs when evaluated in percentage terms.

Figure 10 and Figure 11 show the current and voltage changes of the PV panel and load. As can be seen in Figure 10, the current drawn from the PV panel is 17.65 A in the first region, 21.95 A in the second region, and 8.78 A in the last region. The current value drawn from the panel shows a linear change with the irradiance, and the current increases when the irradiance increases and decreases when the irradiance decreases. With this change, the current of the load at the output also changes. As can be seen from the figure, the load current also shows a direct proportional change according to the PV current. The load current is 6.9 A, 7.69 A, and 4.87 A, respectively.

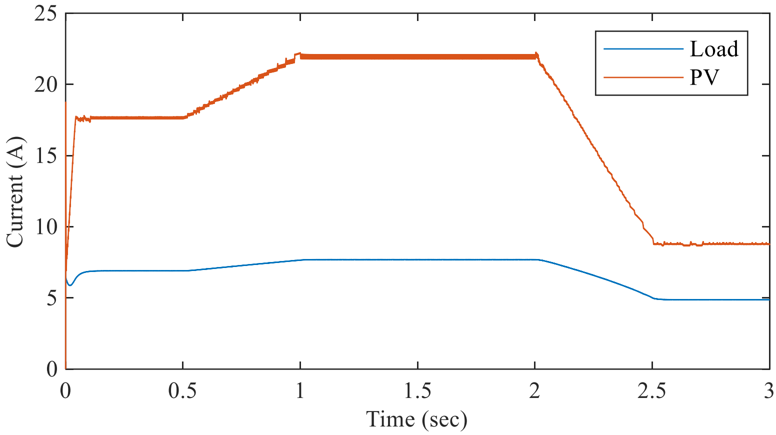



**Figure 10.** PV and load current

Figure 11 shows the PV panel and load voltages. Due to the power conservation law, unlike the current, the load voltage takes higher values than the PV panel. The panel voltage is 295 V on average due to the use of the MPPT algorithm.

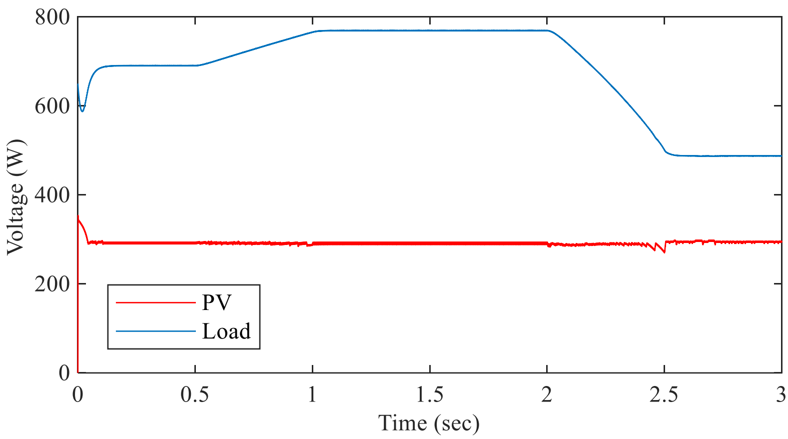



**Figure 11.** PV and load voltage

## 5. CONCLUSION

One of the non-isolated converter types is the SEPIC converter circuit, which can increase or decrease the output voltage according to the input, such as a step-up converter. In addition, the input current fluctuates little. For these reasons, this converter is preferred in photovoltaic system applications. In this study, a 6.4 kW PV system consisting of 30 photovoltaic panels is controlled by a SEPIC converter. The P&O technique is preferred as the PV panel MPPT algorithm. The performance of this system is analyzed with a simulation circuit in the Simulink/MATLAB environment. As a result of the results obtained from the simulation, it is seen that the system reaches the maximum power point in different irradiation conditions. Even if the ambient conditions change, the maximum power that can be produced is drawn from the PV panels. The results show that the combined use of the SEPIC converter and the P&O algorithm gives effective results in PV systems.

## 6. REFERENCES


[1] Ram, J. P., Babu, T. S., & Rajasekar, N. (2017). A comprehensive review on solar PV maximum power point tracking techniques. Renewable and Sustainable Energy Reviews, 67, 826-847.

[2] Walid, K., Sofiane, M., Benbouhenni, H., Hamza, G., & Es-saadi, T. (2023). Application of third-order sliding mode controller to improve the maximum power point for the photovoltaic system. Energy Reports, 9, 5372-5383.

[3] Eltawil, M. A., & Zhao, Z. (2013). MPPT techniques for photovoltaic applications. Renewable and sustainable energy reviews, 25, 793-813.

[4] Pande, P. C., Singh, A. K., Ansari, S., Vyas, S. K., & Dave, B. K. (2003). Design development and testing of a solar PV pump based drip system for orchards. Renewable Energy, 28(3), 385-396.

[5] Mohammed, H. A. Z. (2016, July). Design and implementation of a photovoltaic system used for street lights. In 2016 2nd International Conference on Control Science and Systems Engineering (ICCSSE) (pp. 169-175). IEEE.

[6] Akdeniz, M., & Efe, S. B. (2025). Forecasting of harmonic distortions in MV distribution network caused by illumination devices. Light & Engineering, 33(2), 104–110.

[7] Romero-Cadaval, E., Spagnuolo, G., Franquelo, L. G., Ramos-Paja, C. A., Suntio, T., & Xiao, W. M. (2013). Grid-connected photovoltaic generation plants: Components and operation. IEEE industrial electronics magazine, 7(3), 6-20.

[8] Park, J. H., Kim, H. G., Nho, E. C., Chun, T. W., & Choi, J. (2009, February). Grid-connected PV system using a quasi-Z-source inverter. In 2009 Twenty-Fourth Annual IEEE Applied Power Electronics Conference and Exposition (pp. 925-929). IEEE.

[9] Bhatnagar, P., & Nema, R. K. (2013). Maximum power point tracking control techniques: State-of-the-art in photovoltaic applications. Renewable and sustainable energy reviews, 23, 224-241.

[10] Worku, M. Y., Hassan, M. A., Maraaba, L. S., Shafiullah, M., Elkadeem, M. R., Hossain, M. I., & Abido, M. A. (2023). A comprehensive review of recent maximum power point tracking techniques for photovoltaic systems under partial shading. Sustainability, 15(14), 11132.

[11] Titri, S., Larbes, C., Toumi, K. Y., & Benatchba, K. (2017). A new MPPT controller based on the Ant colony optimization algorithm for Photovoltaic systems under partial shading conditions. Applied Soft Computing, 58, 465-479.

[12] Isen, E., & Sengul, A. (2020). Comparison of maximum power point tracking techniques on photovoltaic panels. Çanakkale Onsekiz Mart University Journal of Graduate School of Natural and Applied Sciences, 6(1), 14-29.
[13] Ahmed, J., & Salam, Z. (2015). An improved perturb and observe (P&O) maximum power point tracking (MPPT) algorithm for higher efficiency. Applied Energy, 150, 97-108.
[14] Sera, D., Mathe, L., Kerekes, T., Spataru, S. V., & Teodorescu, R. (2013). On the perturb-and-observe and incremental conductance MPPT methods for PV systems. IEEE journal of photovoltaics, 3(3), 1070-1078.
[15] Devi, V. K., Premkumar, K., Beevi, A. B., & Ramaiyer, S. (2017). A modified Perturb & Observe MPPT technique to tackle steady state and rapidly varying atmospheric conditions. Solar Energy, 157, 419-426.
[16] Alik, R., & Jusoh, A. (2017). Modified Perturb and Observe (P&O) with checking algorithm under various solar irradiation. Solar Energy, 148, 128-139.
[17] Abdel-Salam, M., El-Mohandes, M. T., & Goda, M. (2018). An improved perturb-and-observe based MPPT method for PV systems under varying irradiation levels. Solar Energy, 171, 547-561.
[18] Majstorović, M., Mršević, D., Đurić, B., Milešević, M., Stević, Z., & Despotović, Ž. V. (2020, March). Implementation of MPPT methods with SEPIC converter. In 2020 19th International Symposium INFOTEH-JAHORINA (INFOTEH) (pp. 1-6). IEEE.
[19] Singh, S., Manna, S., Mansoori, M. I. H., & Akella, A. K. (2020, July). Implementation of perturb & observe MPPT technique using boost converter in PV system. In 2020 international conference on computational intelligence for smart power system and sustainable energy (CISPSSE) (pp. 1-4). IEEE.
[20] Chellakhi, A., El Beid, S., & Abouelmahjoub, Y. (2022). An improved adaptable step-size P&O MPPT approach for standalone photovoltaic systems with a battery station. Simulation Modelling Practice and Theory, 121, 102655.
[21] Kumar, V., & Bindal, R. K. (2022). MPPT technique used with perturb and observe to enhance the efficiency of a photovoltaic system. Materials Today: Proceedings, 69, A6-A11.
[22] Jabbar, R. I., Mekhilef, S., Mubin, M., & Mohammed, K. K. (2023). A modified perturb and observe MPPT for a fast and accurate tracking of MPP under varying weather conditions. IEEE Access, 11, 76166-76176.

[23] Baimel, D., Tapuchi, S., Levron, Y., & Belikov, J. (2019). Improved fractional open circuit voltage MPPT methods for PV systems. Electronics, 8(3), 321.

[24] Sher, H. A., Murtaza, A. F., Noman, A., Addoweesh, K. E., Al-Haddad, K., & Chiaberge, M. (2015). A new sensorless hybrid MPPT algorithm based on fractional short-circuit current measurement and P&O MPPT. IEEE Transactions on sustainable energy, 6(4), 1426-1434.

[25] Yadav, D., Chauhan, R., Gupta, S. K., & Singh, S. N. (2023). Analysis of the factors influencing the performance of single- and multi-diode PV solar modules. IEEE Access, 11, 95507–95525.

[26] R. D. Dongare & B. N. Chaudhari, Design of a Photovoltaic System using MPPT based SEPIC Converter control, in Proc. 2021 2nd Global Conference for Advancement in Technology (GCAT), Bangalore, India, Oct. 1–3, 2021, 1–5.

[27] Alrubaie, A. J., Al-Khaykan, A., Malik, R. Q., Talib, S. H., Mousa, M. I., & Kadhim, A. M. (2022). Review on MPPT techniques in solar system. In 2022 8th International Engineering Conference on Sustainable Technology and Development (IEC), 123–128.

[28] Y. Atia (2009). Photovoltaic Maximum Power Point Tracking Using SEPIC Converter, Engineering Research Journal, Faculty of Engineering, Minoufiya University, 1-9.

# Chapter 2

# From Forest to Value: A Life Cycle Assessment of the Wood Furniture Industry

**Merve CAMBAZOĞLU[1], Sezen COŞKUN [2], Abdullah SÜTÇÜ[3]**

**Abstract**

In the furniture sector, environmentally responsible production plays a crucial role in conserving natural resources and promoting sustainable development. Life cycle assessment (LCA) is among the most widely applied methodologies for evaluating the environmental impacts of processes, offering a comprehensive framework that encompasses all stages from raw material extraction and supply to energy use and product disposal. This study focuses on LCA applications in the furniture industry and highlights their significance in identifying environmental hotspots, guiding strategic decisions, and supporting sustainability-oriented improvements. Strategies such as the use of recycled materials, environmentally friendly surface finishes, sustainable raw material selection, and eco-design approaches have been identified as key areas with high potential to reduce the overall environmental footprint of furniture production. Moreover, the integration of LCA facilitates collaboration with suppliers throughout the product life cycle, extending beyond individual companies to influence broader industry networks. Such collaborative and holistic implementation of LCA not only enhances environmental performance but also contributes to improved operational outcomes and competitiveness within the sector.

**Key words:** LCA, Wooden Furniture, Sustainabilty, Forest Product Industry

[1] Isparta University of Applied Sciences, Faculty of Forestry, Department of Forest Product Industry, Isparta, Türkiye. Sorumlu Yazar: mervecambazoglu@isparta.edu.tr, ORCID: 0000-0001-5456-6454

[2] Eğirdir Vocational School, Isparta University of Applied Sciences, Eğirdir, Isparta, Türkiye. ORCID: 0000-0001-7011-9187

[3] Isparta University of Applied Sciences, Faculty of Forestry, Department of Forest Product Industry, Isparta, Türkiye. ORCID: 0000-0003-4200-917X

## 1. Introduction

Wood-based raw materials stand out among environmentally friendly material options with their renewable properties. Thanks to sustainable forestry, these raw materials offer long-term carbon storage capacity and can be an alternative to fossil fuels (Bergman and Brashaw, 2021). However, additives used in the production process and recycling limitations can reduce environmental benefits (Goldhahn et al., 2021). Therefore, efficient use of resources and effective management of waste are critical for both economic value generation and ecological balance. In this context, it is necessary to develop a more holistic and integrated approach between economic value generation and ecological balance from an environmental sustainability perspective (George et al., 2015).

Life Cycle Assessment (LCA) is a common analytical tool used to assess the environmental impacts of products, processes or services throughout the entire life cycle, from raw material extraction to disposal (ISO, 2006). LCA implementation steps include determining the goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation (Hartini et al., 2019). Studies on LCA in the forest products sector mainly address impacts on global warming potential (GWP), as wood-based resources are mainly biogenic, which facilitates climate change mitigation by transporting fossil fuels through energy recovery or storing carbon in wood products for long periods of time (Faraca et al.,2019).

LCA studies are seen as an important tool for achieving the Paris Climate Agreement's goal of limiting global warming to 1.5 °C by 2050. In this context, the areas of focus in the furniture sector include various topics such as raw material selection, production processes (González-García et al., 2011), recycling and waste management (Petersen and Solberg, 2002), and supply chain management (Sathre and O'Connor, 2010). Thus, it can be said that the LCA approach provides a scientifically based decision support tool for enhancing the environmental sustainability of the furniture sector.

Furniture production consists of many stages, including material extraction, manufacturing, transport, utilisation and end-of-life disposal, each of which contributes to environmental impacts such as greenhouse gas emissions, resource depletion and waste generation. Using LCA methodologies, stakeholders in the furniture industry can systematically identify and quantify these impacts, thus facilitating the development of more sustainable practices and products (González-García et al., 2012). In the furniture industry, attention should be paid to the environmental impacts associated with the product life cycle along the entire value chain, from raw material procurement to furniture production, from use to end-of-life (Yang et al., 2025).

In recent years, the need to assess the environmental impacts of furniture products and to reduce these impacts has been increasingly recognized and has emerged as a priority area in research. LCA has been adopted as an important method that analyzes the environmental performance of a product in a holistic manner, taking into account the entire life cycle of a product, from the acquisition of raw materials to production, distribution, use and disposal at the end of its life (Wu et al., 2018).

Although wood and wood-derived products are generally classified as environmentally sustainable, it should be noted that their actual sustainability depends on issues such as appropriate forest management, production methods, field assembly, distance required for transportation, use of adhesives (Asdrubali et al., 2017). The current wood-based furniture industry has significant development opportunities towards more environmentally friendly approaches (Coloma-Jiménez et al., 2022). This study focuses on wood-based furniture products and aims to understand environmental impacts and identify areas for sustainability-focused improvement.

## 2. Structure Of The Furniture Industry and Wooden Furniture Sector

The global furniture market size is estimated at $568.6 billion in 2024. The market is expected to reach $878.1 billion by 2032, with a CAGR of 5.65%. This growth is supported by increasing housing sales and demand for innovative furniture products, especially in the US, and the country's market is expected to reach approximately $130.2 billion by 2032 (Fortune Business Insights, 2025).

Developed economies such as the USA, Germany and Italy have been leaders in global furniture production for many years. However, in recent years, due to factors such as lower labor costs and more advantageous tax policies, there has been a significant shift in furniture production from developed countries to developing countries (Mexican etc.) (Koridze, 2022). The European furniture industry is a dynamic sector, accounting for approximately 26% of global production (Forrest et al., 2017). In the European Union, in terms of primary materials used in production, wooden furniture constitutes the largest share (57%) of furniture production percentage (Renda, 2014) (Fig. 1). The European market is in a leading position with innovative design, sustainable production, efficient use of natural resources and the use of the latest technologies in production (Koridze, 2022).

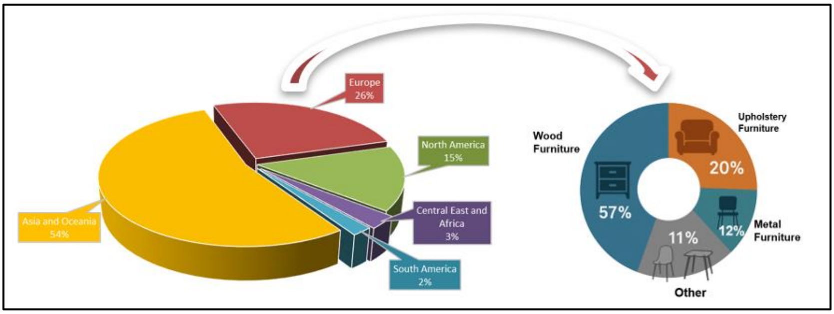



**Fig. 1.** Furniture production rates by continent and European Union furniture type rates

Approximately 51 million tons of furniture are consumed annually worldwide, of which 48.6 million tons are thrown away (Forrest et al., 2017; CSIL and CNFA, 2020). In the European Union, 10.5 million tons of furniture are produced annually, generating 10 million tons of furniture waste, which constitutes more than 4% of municipal solid waste in the European Union (Forrest et al., 2017). The EU Circular Economy Action Plan identifies the replacement of fossil-based products with bio-based products as a priority area due to their renewable and recyclable advantages. Another factor that directs furniture manufacturers to more environmentally friendly production is changing consumer behaviour. A 2020 study in the United States found that 76% of Americans would pay more for eco-friendly furniture (Grand View Research, 2022). This change in consumer behaviour highlights the importance of conducting a comprehensive assessment to improve environmental sustainability in the furniture sector.

Although wood and wood-derived products are generally classified as environmentally sustainable, it should be noted that their actual sustainability depends on issues such as appropriate forest management, production methods, field assembly, distance required for transportation, use of adhesives (Asdrubali et al., 2017). The current wood-based furniture industry has significant development opportunities towards more environmentally friendly approaches (Coloma-Jiménez et al., 2022).

## 3. LCA Approaches in Furniture Industry

Furniture is a crucial sector for sustainable development due to its high environmental impact and potential for sustainable improvement (Yang et al., 2025). The life cycle of furniture products is usually examined in five stages: pre-production, production, distribution, use and disposal (Yang, 2022) (see. Fig.2). Environmental impacts before production are due to the consumption of various raw materials, primarily wood-based materials (Renda, 2014). In the production stage, energy use, chemical consumption and waste generation create significant environmental burdens (Donatello et al., 2017). While transportation, packaging and storage activities are prominent in the distribution process, the impact of the use stage is limited. Furniture waste accounts for more than 4% of total municipal solid waste (MSW) in the EU annually, 80-90% of which is incinerated or disposed of in landfills, while the rest is recycled (Donatello et al., 2014). This negatively affects environmental performance.

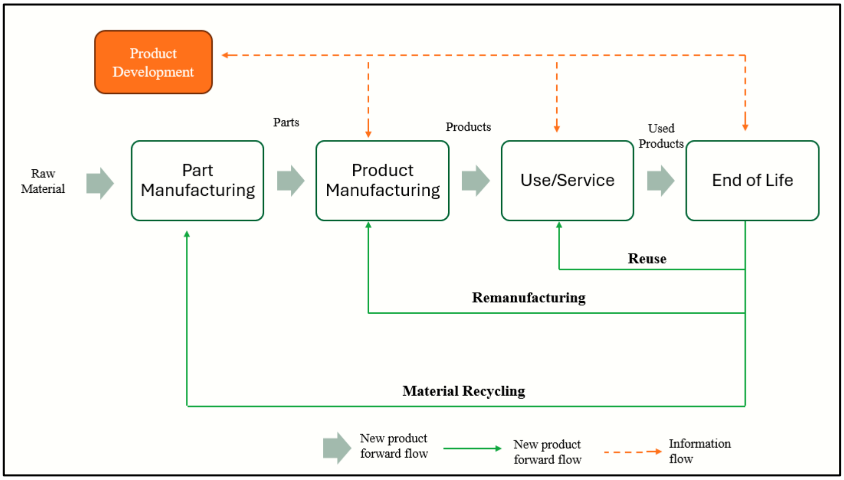
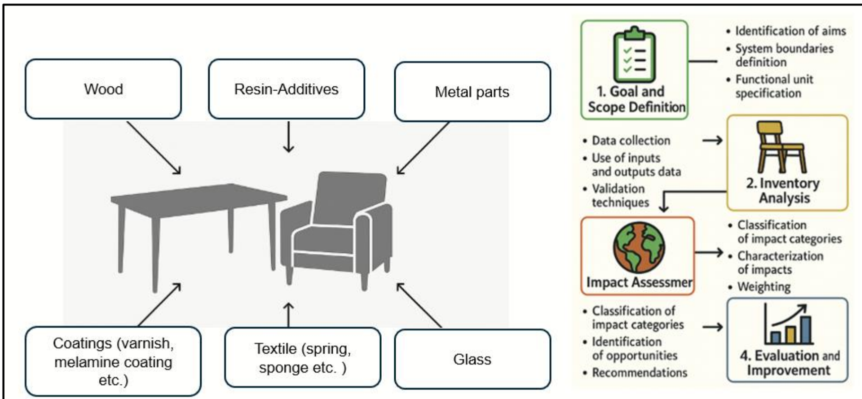



**Fig. 2.** Circular product lifecycle flow (Otieno et al., 2020)

Sustainability strategies developed within the scope of LCA for wood-based furniture products aim to reduce environmental impacts throughout the entire life cycle of the product (Deng et al., 2023). Among these strategies; material substitution through the use of sustainable alternative materials, adoption of production technologies with low environmental impacts, increasing energy and resource efficiency, implementation of circular economy principles such as recycling and reuse, and promotion of responsible waste management practices at the end of the product's life cycle stand out (Vandervaeren et al., 2022). Among the most used wood based materials in the furniture industry are particleboard, oriented strand board (OSB), medium-density fibreboard (MDF), and high-density fibreboard (HDF) (Gonzalez-Garcia et al., 2012; Linkosalmi et al., 2016). Although the use of wood-based materials as raw materials is a more environmentally friendly approach, the negative environmental effects caused by the adhesives and additives used should not be ignored (dos Santos et al., 2014). The impact of raw material selection on environmental performance is summarized in Fig. 3.




| Material | GHG Emissions ($tCO_2e$/tonne) | References |
|---|---|---|
| Aluminum | 22.4 | Adhikari and Ozarska, 2018 |
| Steel (blast furnace production) | 2.55 | Adhikari and Ozarska, 2018 |
| Glass | 1.2 | Chima, 2023 |
| Polyurethane foam | 2.7 | Getzner Werkstoffe, 2019 |
| Polypropylene fabric | 3.68 | Dingil, 2024 |
| Hardwood (rough sawn kiln dried) | 0.23 | Adhikari and Ozarska, 2018 |
| Softwood (rough sawn kiln dried) | 0.234 | Adhikari and Ozarska, 2018 |
| Medium density fibreboard (MDF) | 0.726 | Adhikari and Ozarska, 2018 |
| Particle board | 0.688 | Lao and Chang, 2023 |
| HDF | 0.9 | VHI, 2013 |
| Decorative paper | 1.05 | Tomberlin et al., 2020 |
| Resin (PVA) | 1 | EPDLA, 2017 |

**Fig. 3.** LCA application steps, raw materials used in furniture production and carbon footprint values per ton

While most materials such as steel, aluminum and plastic require high energy input in the production process, the production of timber products (lumber-wood-based panels-furniture) uses much less energy than competitive materials (Adhikari and Ozarska, 2018). LCA practices in a furniture manufacturing facility largely depend on the pre-production environmental impacts of purchased semi-finished products (Wenker et al., 2018). Therefore, it should be noted that the sustainability of furniture production depends on semi-finished products.

The studies compared the environmental impacts of different materials and processes. For example, particleboard with low formaldehyde content performed better environmentally, while biocomposites produced from perennial plants such as hemp fiber can demonstrate better environmental performance due to lower resource consumption. In addition, the evaluation of wood surface coatings has shown that 100% UV varnish is the most environmentally friendly option, and low-density laminate performs 36% better than high-density laminate in terms of environmental impact. Studies evaluating the environmental impact of different production processes indicate that the milling saw stage has the highest impact in wood production, switching from epoxy-based powder coatings to polyester-based powder coatings in metal processing reduces health risks and environmental impacts, and wet white coating in leather processing has a lower environmental impact than traditional chrome coating. Certain furniture products, such as school desks, cribs, work desks, and wardrobes, can cause environmental problems due to the processing of iron parts, the use of MDF, and high electricity consumption during the manufacturing process (Yang et al., 2025).

When studies on the furniture industry and LCA in the literature are generally examined, the majority of them focus on eco-design (Çinar, 2005; González-García et al., 2011, 2012; Mirabella et al., 2014) and production using waste wood (Coloma-Jiménez et al., 2022; de Souza Pinhoo et al., 2023; Russel et al., 2023). Considering that LCA is an effective tool to evaluate the environmental benefits of eco-design strategies in the furniture industry (Forrest et al., 2017) and that sustainable design practices in furniture manufacturing significantly reduce environmental burdens when integrated into the early design stages of LCA and circular material flows (Yang et al., 2025), the contribution of research in this field to reducing environmental impacts and improving design processes is clearly evident. Literature studies reveal several basic strategies to improve the environmental performance of furniture products. Considering that approximately 70% of the environmental impacts of a product are determined at the design stage (Jeswiet and Hauschild, 2005), decisions taken at this stage significantly affect the entire life cycle from production to end-of-life evaluations (Mirabella et al., 2014).

LCA studies in the wood furniture sector have mainly concentrated on three topic themes: wood waste management, eco-design strategies, and the selection of sustainable raw materials. Pinho and Calmon (2023) highlighted the critical role of standardizing LCA approaches to effectively compare environmental impacts across various wood waste treatment scenarios. Similarly, the application of eco-design principles such as material certification, modularity, and supply chain optimization has been shown to reduce life cycle emissions in furniture production (European Commission, 2014). Furthermore, selecting sustainably sourced or recycled wood significantly influences the ecological footprint of wooden furniture, as demonstrated by Yang et al. (2025).

## 4. Conclusion

In this study, LCA studies in the furniture industry were examined at a basic level and the current situation was briefly evaluated. The results of the study show that studies related to sustainability and environmental performance management in the sector are becoming increasingly important. The prominent issues are briefly summarized below and opportunities for development are presented;

1) Current LCA studies and environmental assessments support the further development of biodegradable and bio-based polymers. Careful monitoring of various environmental impacts is essential for both corporate

decision-makers and policymakers. When combined with good practice targets, such monitoring can accelerate ongoing product and process innovation (Patel and Narayan, 2005).

2) Managers should adopt Product Environmental Footprint-based LCA changes to increase production efficiency and reduce the environmental footprint. LCA provides scalable insights that can be effectively applied in other sectors related to furniture to address environmental challenges while increasing economic and operational efficiency (Tessitore et al.2025).
3) Most studies contributing to the literature on this subject are concentrated in Europe and North America. This geographical limitation restricts the understanding of the global scope and environmental impacts of furniture production. Therefore, the widespread adoption of LCA studies will play an important role in determining global potential.
4) Current studies focus on specific stages of the furniture life cycle, placing greater emphasis on the ecodesign and production stages and less on end-of-life scenarios. This gap in the holistic analysis may overlook a significant portion of the environmental impact, including waste generation and emissions throughout the entire value chain. This situation demonstrates the need for a thorough examination of LCA studies conducted in the furniture sector using a holistic approach. .

**REFERENCES**

Adhikari, S., Ozarska, B. (2018). Minimizing Environmental Impacts Of Timber Products Through The Production Process. From Sawmill To Final Products." Environmental Systems Research, 7(1).

Asdrubali, F., Ferracuti, B., Lombardi, L., Guattari, C., Evangelisti, L., & Grazieschi, G. (2017). A Review Of Structural, Thermo-Physical, Acoustical, And Environmental Properties Of Wooden Materials For Building Applications. Building And Environment, 114, 307-332.

Bergman, R. Brashaw, B. (2021). Wood As A Renewable And Sustainable Resource. Chapter 1 In Fpl-Gtr-282, 1-1.

Chima, D. (2023). Life cycle assessment of flat glass and the implications of decarbonising production (Master's thesis, Lund University).

Çinar, H. (2005). Eco-Design And Furniture: Environmental Impacts Of Wood-Based Panels, Surface And Edge Finishes. Forest Products Journal, 55(11), 27-33.

Coloma-Jiménez, M., Akizu-Gardoki, O., Lizundia, E. (2022). Beyond Ecodesign, Internationalized Markets Enhance The Global Warming Potential In The Wood Furniture Sector. Journal Of Cleaner Production, 379, 134795.

CSIL, & CNFA. (2020). CSIL (centre for industrial studies) and CNFA (China national furniture association) World Furniture Outlook.

De Souza Pinho, G. C., Calmon, J. L., Medeiros, D. L., Vieira, D., & Bravo, A. (2023). Wood Waste Management From The Furniture Industry: The Environmental Performances Of Recycling, Energy Recovery, And Landfill Treatments. Sustainability, 15(20), 14944.

Deng, N., Wang, J., Sun, J., Cao, N. (2023). Life Cycle Assessment And Optimization Scenario Of Solid Wood Composite Doors: A Case Study In The East Of China. Science Of The Total Environment, 868, 161494.

Dingil, B. (2024). Life cycle assessment of furniture products: A case study of a chair (Master's thesis, Middle East Technical University (Turkey).

Donatello, S., DE, O. G., & Wolf, O. (2017). Revision of the EU Green Public Procurement (GPP) criteria for Furniture. Technical Report: Final version.

Donatello, S., Moons, H., Cordella, M., Kowalska, M., Kaps, R., & Jrc, O. W. (2014). Revision Of Eu Ecolabel And Eu Green Public Procurement Criteria For Furniture Products.

Dos Santos, M.F.N., Battistelle, R.A.G., Bezerra, B.S., Varum, H.S.A., (2014). Comparative Study Of The Life Cycle Assessment Of Particleboards Made Of Residues From Sugarcane Bagasse (Saccharum Spp.) And Pine Wood

Shavings (Pinus Elliottii). J. Clean. Prod. 64, 345–355. Https://Doi.Org/10.1016/J.Jclepro.2013.06.039.

EPDLA (2017). European Polymer Dispersion and Latex Association: Environmental product declaration of PVA adhesives. Brussels: FEICA – Association of the European Adhesive & Sealant Industry.

European Commission, (2014). For A Cleaner And More Competitive Europe. Brussels, Belgium, 28.

Faraca, G., Tonini, D., Astrup, T. F. (2019). Dynamic Accounting Of Greenhouse Gas Emissions From Cascading Utilisation Of Wood Waste. Science Of The Total Environment, 651, 2689-2700.

Forrest, A., Hilton, M., Ballinger, A., Whittaker, D. (2017). Circular Economy Opportunities In The Furniture Sector. European Environmental Bureau: Brussels, Belgium.

Fortune Business Insights. (2025). Furniture Market Size, Industry Share & Covid-19 Impact Analysis, By Raw Material (Wood, Metal, Plastic, And Others), Category (Indoor and Outdoor), End-User (Residential, Office, Hotel, And Others), And Regional Forecast, 2025–2032. Https://Www.Fortunebusinessinsights.Com/Industry-Reports/Furniture-Market-106357

George, A., George, A. (2008). Impact Of Carbon Trading On Wood Products. Forest And Wood Products Australia.

George, D. A., Lin, B. C. A., Chen, Y. (2015). A Circular Economy Model Of Economic Growth. Environmental Modelling & Software, 73, 60-63.

Getzner Werkstoffe GmbH (2019). Environmental Product Declaration: Sylomer® MDI-based flexible polyurethane foam. https://www.mecanocaucho.com/download/catalog/Sylomer_Environmental_Product_Declaration.pdf .

Goldhahn, C., Cabane, E., Chanana, M. (2021). Sustainability In Wood Materials Science. Philosophical Transactions: Mathematical, Physical And Engineering Sciences, 379(2206), 1-18.

González-García, S., Gasol, C. M., Lozano, R. G., Moreira, M. T., Gabarrell, X., I Pons, J. R., & Feijoo, G. (2011). Assessing The Global Warming Potential Of Wooden Products From The Furniture Sector to Improve Their Ecodesign. Science Of the Total Environment, 410, 16-25.

González-García, S., Lozano, R. G., Moreira, M. T., Gabarrell, X., I Pons, J. R., Feijoo, G., & Murphy, R. J. (2012). Eco-Innovation Of A Wooden Childhood Furniture Set: An Example Of Environmental Solutions In The Wood Sector. Science Of The Total Environment, 426, 318-326.

Hartini, S., Wicaksono, P. A., Prastawa, H., Hadyan, A. F. (2019, August). The Environmental Impact Assessment of Furniture Production Process Using The Life Cycle Assessment. In Iop Conference Series: Materials Science And Engineering (Vol. 598, No. 1, P. 012078). Iop Publishing.

Jeswiet, J., Hauschild, M. (2005). Ecodesign And Future Environmental Impacts. Materials & Design, 26(7), 629-634.

Koridze, N. (2022). World furniture industry. Sosyal Araştırmalar ve Davranış Bilimleri, 8(15), 198-207.

Lao, W. L., & Chang, L. (2023). Comparative life cycle assessment of medium density fiberboard and particleboard: A case study in China. Industrial Crops and Products, 205, 117443.

Mirabella, N., Castellani, V., Sala, S. (2014). Lca For Assessing Environmental Benefit Of Eco-Design Strategies and Forest Wood Short Supply Chain: A Furniture Case Study. The International Journal Of Life Cycle Assessment, 19, 1536-1550.

Otieno, W., Chen, P. H., & Chen, K. J. (2020). Assessing The Remanufacturability Of Office Furniture: A Multi-Criteria Decision Making Approach. Journal Of Remanufacturing, 14(1), 1-16.

Patel M. Narayan R. (2005). How Sustainable Are Biopolymers and Biobased Products? The Hope, The Doubts, And The Reality, Natural fibers, (In) Biopolymers, and biocomposites/edited by Amar K. Mohanty, Manjusri Misra, Lawrence T. Drzal., CRC Press, Taylor & Francis Group

Pinho, A. D. S., Calmon, J. L. (2023). Wood Waste Management Systems Supported By Lca And Material Flow Analysis. *Sustainability*, 15(3), 1854. Https://Doi.Org/10.3390/Su15031854

Plastics Europe (2020). Eco-profiles of the European plastics industry: Ethylene-vinyl acetate (EVA). PlasticsEurope AISBL, Brussels.

Renda, A. (2014) The Eu Furniture Market Situation And A Possible Furniture Products Initiative. Brussels: European Commission, Centre For Industrial Studies (Csil), Centre For European Policy Studies (Ceps), Demetra and Economisti Associati, P. 307. Available At: Https://Www.Ceps.Eu/Wp-Content/Uploads/2015/04/ Final%20report_En.Pdf.

Tessitore, S., Testa, F., Di Iorio, V., & Iraldo, F. (2025). Life Cycle Assessment As An Enabler Of An Environmental Sustainability Strategy Evolution Amid Institutional Pressures: A Best Practice From The Furniture Industry. Cleaner Environmental Systems, 16, 100255.

Tomberlin, D., He, M., & Liang, S. (2020). Environmental performance of decorative laminate materials: A life cycle perspective. Journal of Cleaner Production, 244, 118652. https://doi.org/10.1016/j.jclepro.2019.118652

Vandervaeren, C., Galle, W., Stephan, A., De Temmerman, N. (2022). More Than The Sum Of Its Parts: Considering Interdependencies In The Life Cycle Material Flow And Environmental Assessment Of Demountable Buildings. Resources, Conservation And Recycling, 177, 106001.

VHI (German Wood-based Panel Assoc.). (2013). High-density fibreboard (HDF). Environmental Product Declaration. Institut Bauen und Umwelt (IBU), EPD-VHI-20130021.

Wenker, J. L., Richter, K., Rüter, S. (2018). A Methodical Approach For Systematic Life Cycle Assessment Of Wood-Based Furniture. Journal Of Industrial Ecology, 22(4), 671-685.

Wu, F., Haviarova, E., Helfrich, J. (2018). Life-Cycle Inventory Of Hardwood Lumber School Chair. Department Of Forestry and Natural Resources Purdue University.

Yang, D. (2022). The Application Of Life Cycle Assessment In Sustainable Furniture System Design. In *Ergonomics In Design, Proceedings Of 13th Ahfe International Conference On Ergonomics In Design* (Vol. 47, No. 47, Pp. 590-600). Ahfe Open Access.

Yang, D., Vezzoli, C., & Su, H. (2025). Comprehensive life cycle assessment of 25 furniture pieces across categories for sustainable design. *Scientific Reports*, *15*(1), 13968.

# Chapter 3

## Precautionary Measures in Working with Hazardous Chemical Substances

**Ata Yiğit TAŞKAYA[1], Aslı Ece ACAR FİLİZCİ[2], Dilek ÖZTAŞ[3], Ergün ERASLAN[4]**

**Abstract**

Chemical substances are indispensable inputs in industry and laboratories, yet they pose significant risks due to flammability, explosivity, toxicity, and environmental impacts. This review synthesizes Turkish legislation and recent sectoral studies to specify actionable precautions at three levels: (i) legislative and risk-management foundations, (ii) engineering and organizational controls with personal protective equipment as a last resort, and (iii) good practices for high-risk settings. Evidence indicates that collective measures—substitution, closed systems, local exhaust ventilation, and independent protection layers—are most effective when paired with routine exposure measurements, training, and occupational health surveillance; in their absence, risk reduction is limited. Workplace-specific analyses using Fine–Kinney and ETA/LOPA consistently lower initiating-event frequencies; consequence reduction additionally requires design choices that address detection time and released mass. In Türkiye, the "Regulation on Health and Safety Measures in Working with Chemical Substances" provides the legal foundation for this integrated approach, operationalized here through checklists and templates [13].

[1] Master's Student, Ankara Yıldırım Beyazıt University, Institute of Science, Occupational Health and Safety, Ankara, Turkey, ORCID:0009-0004-4291-3630, taskayatayigit17@gmail.com

[2] Dr., Occupational Health and Safety, Ankara, Turkey, ORCID:0000-0002-2323-7655, aslieceacar@gmail.com

[3] Prof. Dr., Ankara Yıldırım Beyazıt University, Faculty of Medicine, Department of Public Health, Ankara, Turkey, ORCID:0000-0002-8687-7238, doztas@aybu.edu.tr

[4] Prof. Dr., Ankara Yıldırım Beyazıt University, Institute of Science, Department of Occupational Health and Safety, Ankara, Türkiye, ORCID:0000-0002-5667-0391, eraslan@aybu.edu.tr

## Introduction

The global production and utilization of millions of chemicals have significantly facilitated modern life; however, they also pose serious health and safety risks, particularly through chronic exposure pathways [4, 6]. Establishing sustainable and safe working conditions becomes challenging without a comprehensive consideration of the physical (flammability, explosiveness, reactivity), health-related (acute and chronic toxicity, carcinogenicity, mutagenicity), and environmental dimensions of chemical hazards [3]. This article aims to provide a holistic roadmap that spans from the legal framework to field-level practices.

## Contribution and Limitations of the Study:

This review integrates legislation, process safety, and industry practices under a single framework, offering actionable examples and control checklists. As a limitation, it should be noted that the applicability of the proposed measures must be verified in situ, depending on the type of enterprise, chemical inventory, and specific process conditions.

## Methodology and Scope of the Review

This study is based on legal texts, academic publications, and industry reports that outline risk assessment and process safety methodologies, including the Fine–Kinney method and techniques such as Event Tree Analysis (ETA) and Layer of Protection Analysis (LOPA) [3, 9]. Concrete examples of good practices and control checklists have been developed based on case studies from fuel stations, laboratories (forensic toxicology, organic chemistry, drinking water analysis), textile production, and compressor rooms [1, 2, 4, 8, 10, 11, 14].

## Conceptual Framework and Regulatory Context

The regulation defines the employer's primary obligation as "preventing exposure; or, if not possible, reducing it to the minimum level" and mandates the implementation of a formal risk assessment process [13]. This assessment must consider the hazardous properties of the chemical, the Turkish-language Safety Data Sheet (SDS), exposure level and duration determined by accredited laboratory measurements, occupational and biological limit values, as well as the potential interactions between multiple chemicals (Article 6).

The hierarchy of control measures, as outlined, is as follows: substitution, process/engineering controls, collective protection methods, and as a last resort, personal protective equipment (PPE) (Article 7). Furthermore, it is compulsory to repeat exposure measurements following any process modifications and to maintain ongoing health surveillance [9, 13].

**Classification, Labeling, and Hazard Communication**

The processes of chemical classification and labeling, access to Safety Data Sheets (SDS), proper storage and transportation, waste disposal, and record-keeping/documentation form the backbone of organizational control mechanisms [3]. The effective implementation of REACH and its Turkish counterpart KKDIK regulations in operational practices is reinforced through institutionalized information flow across the supply chain and the systematic adoption of substitution decisions [9].

**Risk Management and Analysis Methods**

The fundamental steps in chemical risk management include hazard identification, evaluation of exposure routes (inhalation, dermal, ingestion/injection), quantitative or qualitative risk assessment, and monitoring of control measures. The Fine–Kinney method is a highly practical tool with strong field applicability; for instance, in a drinking water laboratory, it was demonstrated that improved SDS literacy and proper use of PPE significantly reduced risks previously classified as “intolerable” or “substantial” [10].

From a process safety perspective, methods such as Event Tree Analysis (ETA) and Layer of Protection Analysis (LOPA) are employed to analyze scenarios involving flash fires, jet fires, explosions, and toxic releases. The influence of Independent Protection Layers (IPLs) on both the frequency and severity of such events is evaluated in an integrated manner [5].

**Table 1.** Hierarchy of Controls and Example Applications

| Level | Example | Note |
|---|---|---|
| **Substitution** | Use of low-benzene fuel instead of benzene; less hazardous coating compounds instead of chromium(VI) | Risk is reduced at the source |
| **Process/Engineering** | Closed systems, LEV, inerting, ESD/interlocks, leak/gas detection systems | Performance verification is essential |
| **Collective Protection** | Ventilation, area isolation, secondary containment/sealing | Verify effectiveness through measurement |
| **PPE (Supplementary)** | A1/AX cartridge respirators, chemical-resistant gloves, eye/face protection | Last resort in the control hierarchy |

**Engineering and Process Safety Measures**

Source control is fundamental: key measures include closed systems, local exhaust ventilation (LEV), inerting, process automation (such as ESD and interlocks), rapid detection and isolation, containment basins, and proper material and pipeline design. In a facility storing 1,3-butadiene, evaluated Independent Protection Layers (IPLs) were found to reduce the frequency of incidents; however, when detection time was short and the mass released remained constant, impact distances did not change significantly in non-explosive scenarios. This finding underscores the necessity of designs that aim not only to reduce frequency but also to mitigate consequences [5, 12].

**Table 2.** Summary of LOPA/IPL Scenarios (Representative)

| Scenario | Initiating Event | IPL | Expected Effect |
| --- | --- | --- | --- |
| Jet fire | Flange leak + ignition | Flame detection + rapid shutdown | Frequency decreases; radiation impact distance is minimally affected |
| Toxic release | Tank top valve failure | Gas detection + automatic isolation | Frequency decreases; if mass is not reduced, impact distance remains similar |
| Explosion | Vapor cloud + ignition | Pressure relief + explosion vent panel | Overpressure impact is reduced; distance shortens |

**Organizational and Administrative Measures**

Chemical inventory management, labeling, access to Safety Data Sheets (SDS), compliant storage and transportation, cleaning and waste handling, exposure monitoring and medical surveillance, training, and recordkeeping/documentation are the foundational pillars of operational safety at the enterprise level [3, 9]. The need for institutionalization and regulatory guidance is particularly evident in small and medium-sized enterprises (SMEs) [15].

**Personal Protective Equipment (PPE)**

PPE does not replace collective protective measures; rather, it complements them. Training and proper selection are critical when choosing respiratory protection, gloves, eye/face protection, and chemical-resistant work clothing. In laboratories with VOC (volatile organic compound) risks, fume hoods and adequate ventilation must be combined with personal exposure monitoring and the use of appropriate PPE [13, 14].

**Table 3.** Example PPE Selection Matrix (Summary)

| Chemical | Type of Exposure | Recommended PPE | Note |
|---|---|---|---|
| Acid/base solutions | Splash | Face shield + chemical goggles; nitrile/elastomer gloves | Glove material must comply with SDS |
| Aromatic solvents (BTEX) | Vapor + dermal | A1/AX cartridge half/full face respirator; chemically resistant gloves | Cartridge service life plan required |
| Oxidizing agents | Splash | Goggles/face shield; PVC/Neoprene gloves | Compatible storage/separation is essential |

**Monitoring, Measurement, and Health Surveillance**

Employers are responsible for conducting regular measurement and analysis of hazardous chemicals, ensuring repetition when working conditions change, and maintaining compliance with occupational and biological exposure limits as well as health surveillance programs [13]. At fuel stations, monitoring of BTEX compounds, adherence to safety procedures, and the use of appropriate PPE contribute significantly to risk reduction [4].

**Storage, Transportation, and Waste Management**

Chemicals must be stored in accordance with their compatibility; oxidizers, acids, bases, organics, and peroxide-forming substances should be segregated. Proper labeling and access to Safety Data Sheets (SDS), secondary containment, adequate ventilation, and fire protection systems are essential [13]. In organic chemistry laboratories, regular segregation of solvents and wastes, along with emphasizing carcinogenic hazards, is particularly important [14]. In textile finishing facilities, automatic dosing systems and well-ventilated storage areas serve as good practice examples [2, 8].

**Training, Labeling, SDS, and Hazard Communication**

Hazard identification, label and SDS literacy, emergency response/first aid instructions, and clear signage and labeling practices are key components of regular training programs [3, 13].

**Table 4.** Sample Annual Training Matrix

| Target Group | Module | Frequency | Content Note |
|---|---|---|---|
| All employees | SDS/label literacy | 12 months | Pictograms, H/P statements, storage compliance |
| Laboratory | Fume hood and spill response | 6 months | Spill kit, waste classification |
| Field (fuel stations) | BTEX exposure control | 6 months | Monitoring forms/limits, PPE implementation |
| Maintenance/process | LOPA/IPL awareness | 12 months | Barriers, testing/validation |

**Good Practices in High-Risk Areas**

**Fuel Stations (BTEX):**

Exposure to benzene, toluene, ethylbenzene, and xylene primarily occurs via inhalation and dermal contact. Due to benzene being classified as a Group 1 human carcinogen, implementation of proper ventilation, appropriate PPE, workplace air monitoring, and strict adherence to safety procedures is mandatory [4].

**Laboratories:**

In forensic toxicology laboratories, tracking the shelf-life of peroxide-forming chemicals, securing gas cylinders, conducting regular inspections, providing spill kits, and maintaining an emergency response plan are essential [1]. In organic chemistry labs, controlling VOC exposure requires the use of fume hoods, appropriate PPE, and robust waste management systems [14]. In drinking water laboratories, the effectiveness of SDS and PPE compliance in reducing risk classes has been demonstrated through the Fine–Kinney method [10].

**Textile Industry:**

Dust-based dyes, bleaching agents such as hypochlorite/peroxides, and finishing chemicals pose risks of inhalable dust, VOC exposure, and fire. Key preventive measures include local exhaust ventilation (LEV) during powder weighing, automated chemical dosing systems, appropriate storage/ventilation, training, and consistent PPE use [2, 8].

**Chemical Storage Facilities:**

Applications of ETA and LOPA methodologies have shown that Independent Protection Layers (IPLs) reduce event frequencies; however, when detection time and release quantity remain unchanged, the impact distances—except in explosion scenarios—are only marginally affected [5, 12].

**Compressor Rooms and Pressurized Air Lines:**

Compliance with SDS guidelines for compressor oils/chemicals, use of hearing protection, and isolated work zones are essential. Periodic inspections and maintenance procedures must be consistently applied for pipelines and storage tanks [11].

**Emergency Management and First Aid**

Emergency response plans, scenario-based drills, and chemical spill procedures—including area isolation, appropriate PPE use, containment/absorption, waste management, and post-incident reporting—must be documented and readily accessible. In laboratories, emergency showers/eyewash stations, spill kits, and warning signs are fundamental safety requirements [1, 3, 9].

**Performance Monitoring and Continuous Improvement**

**Leading indicators** include: SDS accessibility rate, training completion rate, frequency of LEV (Local Exhaust Ventilation) performance tests, and the number of IPL (Independent Protection Layer) tests/validations. **Lagging indicators** include: exceedance of exposure limits, frequency of spill incidents, and records of occupational accidents or diseases. Management reviews should be conducted using measurable objectives and the PDCA cycle (Plan–Do–Check–Act) as a structured approach to ensure continuous improvement [9].

**Conclusion**

Safe handling of hazardous chemicals relies on the consistent and integrated application of legal compliance, risk analyses, and layered controls encompassing engineering, organizational, and personal measures. The regulation defines clear minimum requirements for substitution, collective protection, monitoring, training, and health surveillance [13]. Sector-specific studies demonstrate that BTEX exposure can be effectively managed through procedural adherence and PPE use; that fume hoods, LEV systems, automated dosing, and disciplined storage practices are effective in laboratory and textile environments; and that in process safety, the IPL/LOPA approach should address both the frequency and consequences of potential incidents [2, 4, 5].

**Policy and Practice Recommendations**

- Conduct process-based evaluations of substitution and closed-system alternatives.
- Validate the performance of LEV and general ventilation systems (through measurement and verification).
- Review the frequency and severity mitigation capabilities of barriers using ETA/LOPA methods.
- Deliver periodic and hands-on training programs on SDS literacy, labeling, and chemical compatibility.
- Update authorized laboratory measurements and health surveillance protocols following management of change (MOC) processes.
- Ensure accessibility of spill and first-aid equipment, and standardize emergency drills.

**Appendix A. Fine–Kinney Risk Assessment Template (Summary)**

***Table 5.*** *Fine–Kinney Risk Assessment Template (Summary)*

| **Activity** | **Hazard** | **Probability** | **Frequency** | **Severity** | **Risk** | **Control / Measure** |
|---|---|---|---|---|---|---|
| Acid titration | Splash | 3 | 0.5 | 15 | — | Eyewash station, face shield; indicator training |
| BTEX filling | Vapor inhalation | 3 | 1 | 15 | — | Cartridge replacement plan, ventilation, operating procedure |
| Sample collection | Skin contact | 6 | 6 | 7 | — | Glove selection, written instructions |

**Appendix B. Comprehensive Spill Response Checklist**

- Alert and isolate the area: Notify nearby personnel and restrict access using warning signs, barricades, or caution tape.
- Assess the situation: Identify the spilled substance using labels or the Safety Data Sheet (SDS).
- Don't appropriate PPE: Wear suitable personal protective equipment (PPE) based on the substance's hazard classification (e.g., gloves, goggles, respirator, chemical suit).
- Stop the source *(if safe to do so)*: Turn off valves, upright tipped containers, or stop the leak to prevent further release.

- Deploy containment barriers: Use absorbent socks, booms, or spill berms to prevent spreading.
- Apply absorbent material: Cover the spill with suitable absorbents (e.g., pads, granules) compatible with the chemical type.
- Prevent environmental release: Block drains and prevent the spill from reaching water sources or ventilation systems.
- Collect and dispose of waste: Place used absorbents, PPE, and contaminated materials into proper hazardous waste containers.
- Label the waste: Clearly mark containers with the appropriate hazard label and description based on waste classification.
- Decontaminate surfaces: Clean the affected area using appropriate neutralizing agents or cleaning protocols.
- Report the incident: Complete a formal spill/incident report including time, location, substance, volume, and personnel involved.
- Conduct root cause analysis: Use appropriate methods (e.g., 5 Whys, Fishbone Diagram) to identify the underlying cause.
- Review emergency plans: Evaluate the response and identify gaps in training, procedures, or equipment.
- Restock supplies: Replace used spill kits, PPE, or materials immediately.
- SDS consulted and updated if needed.
- Training records updated for involved personnel.
- Equipment inspection and maintenance logs reviewed.
- Management notified and corrective actions initiated.

**References**

[1] Ünel, F., & Yıldız, Z. (2023). Potential chemical hazards and necessary occupational health and safety measures in forensic toxicology laboratories. *Karaelmas Journal of Occupational Health and Safety*, 7(3), 119–127. https://dergipark.org.tr/tr/pub/kisgd/issue/80877/1266221

[2] Çoban, B. (2019). *Examination of various chemicals and dyes used in the textile industry in terms of occupational health and safety* (Master's thesis, Ege University). Ege University Institutional Repository. https://acikerisim.ege.edu.tr/items/423d298d-916a-4a5c-ae2a-e80194f1518b

[3] Engür, M. O. (2006). Organizational control measures in workplaces using chemicals. *Journal of the Faculty of Forestry Istanbul University*, 56(2), 61–70. https://dergipark.org.tr/tr/pub/jffiu/issue/18715/198803

[4] Şentürk, K., & Karahalil, B. (2024). Chemical exposure of employees in fuel stations. *Journal of Ankara University Faculty of Pharmacy*, 48(1), 251–258. https://dergipark.org.tr/tr/pub/jfpanu/issue/80375/1347498

[5] Taşdemir, O., & Çetinyokuş, S. (2024a). Risk analysis in a chemical storage facility: Impact of independent protection layers. *Gazi University Journal of Engineering and Architecture Faculty*, 39(2), 497–508. https://dergipark.org.tr/tr/pub/gazimmfd/article/1118503

[6] Demirci, G., Ateş, F. M., & Fandaklı, S. (2023). Hazards caused by chemicals in the workplace and their effects on human health. *Bayburt University Journal of Science*, 6(2), 242–253. https://dergipark.org.tr/tr/pub/bufbd/article/1326123

[7] Çakar, M. (2024). Hazards of chemicals and their impact on occupational safety. *Journal of Northern Aegean Technical Sciences and Technology*, 1(1), 46–56. https://dergipark.org.tr/tr/pub/ketbt/issue/88501/1588065

[8] Yılmaz, O. (2017). *Chemical risk factors in the textile industry and analysis of Social Security Institution (SSI) inspection data* (Master's thesis, Cumhuriyet University). Thesis Archive. https://tezara.org/theses/479213

[9] Demir, S. (2010). *Occupational health and safety management of hazardous chemical substances* (Master's thesis, Istanbul Technical University). Council of Higher Education Thesis Center. https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=iPJSF7LLzqvE0EnP9d3PAQ

[10] Albayrak, S. (2019). *Occupational health and safety assessment of hazardous chemicals: A case study in a drinking water treatment laboratory* (Master's thesis, Üsküdar University). Council of Higher Education Thesis Center.

https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=w2hz9AMufmbK8LDOJLkKMg
[11] Çakır, A., Demircan, N., Kocabaş, H. R., & Dilsiz, G. (2022). Occupational health and safety evaluation of compressor rooms and pressurized air transmission lines in an underground mining operation. *Karaelmas Journal of Occupational Health and Safety*, 6(1), 15–30. https://dergipark.org.tr/tr/pub/kisgd/issue/69591/1049517
[12] Taşdemir, O., & Çetinyokuş, S. (2024b). Risk analysis in a chemical storage facility: Impact of independent protection layers. *Gazi University Journal of Engineering and Architecture Faculty*, 39(1), 497–508. https://dergipark.org.tr/tr/pub/gazimmfd/issue/77185/1118503
[13] Republic of Türkiye Ministry of Labour and Social Security. (2013). *Regulation on health and safety precautions in working with chemical substances* (Official Gazette No. 28733). https://mevzuat.gov.tr/File/GeneratePdf?mevzuatNo=18709&mevzuatTur=KurumVeKurulusYonetmeligi&mevzuatTertip=5
[14] Yavuz, Ş. (2020). Assessment of health and safety risks of chemicals used in organic chemistry laboratories. *OHS Academy*, 3(2), 47–58. https://dergipark.org.tr/tr/pub/ohsacademy/issue/58713/793954
[15] Doğan, F. (2024). Chemical risk factors in terms of occupational health and safety. *Premium e-Journal of Social Sciences*, 8(39). https://pejoss.com/index.php/pub/article/view/446

# Chapter 4

# Types of Personal Protective Equipment (PPE)

**Vuslat Beyza TUNÇKILIÇOĞLU[1], Aslı Ece ACAR FİLİZCİ[2], Dilek ÖZTAŞ[3], Gerçek Budak[4], Ergün ERASLAN[5]**

## 1. Introduction

With the advancement of industrialization, rapid changes in working life have led to the modernization of production processes and increased complexity in work operations. These developments have created new physical and psychological risks and threats for employees. As a result, there has been a significant rise in occupational accidents and diseases, leading to serious societal consequences.

The growing importance of occupational safety methods has become evident alongside the progression of industrialization (Kartal, 2016). Through the enactment of Law No. 6331 on Occupational Health and Safety, various responsibilities have been established to ensure that employees can work in safe and healthy environments. These responsibilities include providing occupational training, supplying personal protective equipment (PPE), and implementing machine safety guards. In accordance with this legislation, workplace physicians and occupational safety specialists are responsible for delivering necessary training, conducting regular monitoring, and implementing preventive measures.

[1] Master's Student, Ankara Yıldırım Beyazıt University, Institute of Science, Occupational Health and Safety, Ankara, Turkey, ORCID: 0009-0007-7847-5961, vuslat657@gmail.com
[2] Dr., Occupational Health and Safety, Ankara, Turkey, ORCID:0000-0002-2323-7655, aslieceacar@gmail.com
[3] Prof. Dr., Ankara Yıldırım Beyazıt University, Faculty of Medicine, Department of Public Health, Ankara, Turkey, ORCID:0000-0002-8687-7238, doztas@aybu.edu.tr
[4] Doç. Dr., Ankara Yıldırım Beyazıt University, Faculy of Engineering, Industrial Engineering, ORCID: 0000-0003-3209-0875, gbudak@aybu.edu.tr
[5] Prof. Dr., Ankara Yıldırım Beyazıt University, Institute of Science, Department of Occupational Health and Safety, Ankara, Türkiye, ORCID:0000-0002-5667-0391, eraslan@aybu.edu.tr

**Figure 1.** Types of Personal Protective Equipment (PPE)

The primary objective of occupational health and safety (OHS) practices is to minimize the occurrence of workplace accidents and to create a safe environment for employees. Until the 21st century, awareness of OHS was relatively limited; however, with the implementation of training programs, machinery safeguards, and personal protective equipment, a greater level of awareness has been achieved, and the importance of OHS has significantly increased over time. The provision of personal protective equipment aims to eliminate risks or bring potential hazards under control at their source.

### 1.1. Personal Protective Equipment (PPE)

Personal protective equipment (PPE), which plays a significant role in reducing occupational accidents and diseases, is one of the most critical components of occupational health and safety (OHS). This section aims to provide a detailed overview of PPE by compiling information from the existing literature. In Türkiye, there are various laws and regulations regarding occupational health. The Law No. 6331 on Occupational Health and Safety came into force in June 2012.

According to the “Regulation on Personal Protective Equipment” published in the Official Gazette dated 29 November 2006 and numbered 26361, and within the scope of Law No. 6331 on Occupational Health and Safety, personal protective equipment is defined as:

1. All tools, instruments, equipment, and devices designed to be worn, held, or carried by the employee to protect them against one or more health and safety risks arising from the work being performed.

2. Equipment composed of devices, instruments, or materials assembled by the manufacturer to function as a whole in order to protect the individual against one or more risks.
3. Protective devices, instruments, or materials that are used together with equipment worn or carried for purposes other than protection, whether detachable or not.
4. Interchangeable components that are necessary for the comfortable and functional operation of PPE and are intended solely for use with such equipment.
(Mevzuat Bilgi Sistemi, 2012)

## 2. Types of Personal Protective Equipment

Personal protective equipment (PPE) refers to all tools, materials, or devices that can be worn, carried, or attached to protect employees against potential risks in the workplace, within the scope of occupational health and safety measures (Yılmaz, 2025). The provision of PPE is the responsibility of the employer. Employers are required to provide employees with appropriate training and information regarding the use of PPE. Furthermore, they are obliged to encourage the regular and proper use of PPE among employees (Yılmaz, 2025). Employees, in turn, are responsible for using the PPE provided to them.


**Figure 2.** The Importance of Personal Protective Equipment Materials

According to various studies, personal protective equipment (PPE) has been shown to significantly reduce workplace accidents. However, a critical point to note is that PPE must be selected in accordance with its intended purpose. The type of personal protective equipment varies depending on the working environment and the specific nature of the job being performed.

### 2.1. Head Protection (Safety Helmets)

Head injuries are of critical importance and can be life-threatening. A head protector must be selected in accordance with the characteristics of the workplace and the requirements of the job. Safety helmets are used to protect the head area against electric shocks, metal splashes, burns, impacts, and collisions with objects.

The areas where safety helmets are commonly used include:

- Construction work
- Road construction and maintenance
- Mining
- Shipbuilding
- Blacksmithing and foundry work
- Industrial furnace and machine operations
- Workplaces with a high risk of explosion

**Figure 3.** Examples of Safety Helmets

There are several important considerations in the proper use of safety helmets. Helmets must not be exposed to deformation or conditions that would compromise their performance. Proper storage and maintenance are also critical. Maintenance instructions are provided by the manufacturer, and users must follow these guidelines accordingly. Usage and maintenance instructions for safety helmets are as follows:

a) The helmet should be adjustable or properly fitted to the user's head size.

b) Deformed helmets must not be used.

c) Helmets must be replaced immediately if exposed to electric shock, impacts, accidents, or chemical substances.

d) No additional parts should be attached to the helmet, and existing parts should not be removed.

e) Solvents, paint, or adhesive labels should not be applied unless permitted by the manufacturer’s instructions.

f) If the helmet is to be used with accessories such as earmuffs or lamps, these accessories must be compatible with the helmet and must not impair its protective function.

g) Helmets should not be stored under direct sunlight.

h) Helmets should be kept in a cool and dark environment.

i) Helmets have both shelf life and service life, which must be strictly followed.

j) To prolong the service life of a helmet, regular maintenance should be conducted. Cleaning may be done using lukewarm water and a mild detergent solutio

k) The helmet must be used strictly in its original form. Modifications such as painting, applying stickers, or drilling ventilation holes are strictly prohibited (T.C. Ministry of Labor and Social Security [ÇSGB], 2025).

### 2.2. Hearing Protectors

Various types of hearing protectors are available to prevent hearing damage caused by noise in the workplace (Beşer, 2019). When noise levels exceed 85 decibels, the use of hearing protection becomes mandatory. However, not only the intensity (dB) but also the frequency of the noise plays a critical role. Low-frequency noise, in particular, requires more effective sound insulation.

Hearing protectors are categorized into three types: earplugs, earmuffs, and helmet-mounted earmuffs.

**Figure 4.** Hearing Protection Equipment

Earplugs must comply with Directive 89/686/EEC and bear the CE marking. They should meet the standards of TS EN 352-2. Earplugs should be corded and disposable. The average noise reduction rating must be above 28–30 decibels.

Earmuffs must comply with TS EN 352-1 standards and be CE certified. Helmet-mounted earmuffs should meet the TS EN 352-3 standards and be CE marked. These earmuffs must be easily attachable to the helmet, and the inner padding should be replaceable.

Common usage areas include:

a) Ground services at airports

b) Workplaces where heavy machinery is used

c) Industrial environments involving pressing operations

d) Areas where various types of drills are used

### 2.3. Hand and Arm Protectors

Employees must use appropriate protective gloves to avoid or minimize risks posed by chemicals, burns, electric shocks, abrasions, cuts, punctures, and other hazardous materials. In addition to gloves, protective equipment has also been designed for the arms. Protective gloves must not harm the user and should be specifically designed for the nature of the task being performed.

All types of protective gloves must comply with TS EN ISO 21420 standards. The relevant standards for protective gloves are provided in the table below.

Table 1. Standards Related to Protective Gloves

| Standard | Description |
|---|---|
| TS EN ISO 21420 | Protective gloves (General requirements and test methods) |
| TS EN 388+A1 | Protective gloves against mechanical risks |
| TS EN ISO 374-1 | Protective gloves against dangerous chemicals and microorganisms (Terminology and performance requirements for chemical risks) |
| TS EN ISO 374-5 | Protective gloves against dangerous chemicals and microorganisms (Terminology and performance requirements for biological risks) |
| TS EN 407 | Protective gloves against thermal risks (heat and/or fire) |
| TS EN 421 | Protective gloves against ionizing radiation and radioactive contamination |
| TS EN 511 | Protective gloves against cold |
| TS EN 659+A1 | Protective gloves for firefighters |
| TS EN 12477 | Protective gloves for welders |
| TS EN 60903 | Gloves and sleeves of insulating material for working under voltage |


**Figure 5.** Types of Hand and Arm Protective Equipment

**2.4. Respiratory Protective Equipment**

Respiratory protective equipment, such as masks, aim to reduce exposure to harmful or toxic gases, dust, fine particles, and hazardous vapors by filtering them out. Employees must use masks suitable for their specific working environment. The provision of protective masks is the employer's responsibility, and employees must be properly informed about their correct usage. Respiratory protective equipment is generally divided into two categories: dust masks and gas masks.

**2.4.1. Dust Masks**

Dust masks are designed to protect workers from inhaling harmful dust particles present in the working environment. Depending on the conditions in the workplace, masks manufactured in accordance with TS EN 149 standards must be selected. Initially, personal exposure measurements must be conducted in the workplace to determine the level of exposure. Based on these results, the appropriate type of dust mask can be chosen. The types of dust masks are as follows:

- FFP1 Type: Effective up to 4 times the occupational exposure limit
- FFP2 Type: Effective up to 12 times the occupational exposure limit
- FFP3 Type: Effective up to 50 times the occupational exposure limit

Figure 6. Types of Dust Masks

When using dust masks, the inner surface of the mask should not be touched. After use, masks should be properly sealed in packaging or stored in a zip-lock bag.

**2.4.2. Gas Masks**

Gas masks are used to prevent the inhalation of harmful and/or toxic gases. These masks must be produced in accordance with the relevant standards: TS EN 136 for full-face masks and TS EN 140 for half-face masks.

**Figure 7.** Respiratory Protective Equipment – Example of Full-Face Gas Mask

Gas masks are equipped with filters that must be replaced periodically based on the concentration and type of gas exposure in the working environment. If air leakage occurs inside the mask, it must be repositioned properly on the face and, if necessary, secured with head straps. Masks should be appropriately fitted to the user's face and must be provided by the employer (BİMA).

### 2.5. Body Protectors

Protective work clothing plays a crucial role in ensuring occupational safety. Depending on the nature of the job, the level of protection provided by work clothing may vary. It is the responsibility of the employer to supply suitable protective garments to employees (İsbu, 2025).

The relevant protective clothing standards are listed below:

- EN 343: Standard for rainwear. Necessary for workers operating in rainy, wet, or humid environments.
- EN 467: Standard for aprons used when working with liquid (fluid) chemicals.
- EN 465: Protective clothing standard for chemical resistance.
- EN 20471: Standard for high-visibility clothing, especially for workers in low-light or high-glare conditions.
- EN ISO 11612: Standard for protective clothing (excluding hands) against heat and flame.
- EN 469: Standard specifically designed for firefighters, offering protection in extreme heat and flame conditions.
- EN ISO 11611: Standard for protective clothing used in welding, offering protection against small splashes of molten metal.
- EN 1149: Protective clothing standard for dissipating electrostatic charges.
- EN 61482: Clothing standard offering protection against thermal hazards of electric arc exposure.
- EN 412: Standard for protective aprons designed to prevent cutting injuries.
- EN 464: Protective clothing standard against liquid and/or gaseous chemicals.
- EN 1073-1: Standard for protective garments preventing radioactive contamination.


**Figure 8.** Types of Protective Work Equipment

The EN 340 standard is a general standard for protective work clothing. All protective garments must comply with the EN 340 standard. However, this standard alone does not provide specific protection features and should be used in conjunction with other relevant standards based on the type and level of risk present in the working environment (Lindstrom, 2025).

### 2.6. Foot Protection

Protective work footwear must be selected based on the nature of the task and the individual worker's needs. These shoes should not be used outside the work environment and must be aired after use. If the shoes are torn, punctured, or otherwise damaged, they should be replaced with new ones. Cleaning and maintenance of protective footwear should be carried out at regular intervals.

Workers wearing safety shoes should use **cotton socks** to prevent fungal infections and excessive sweating.

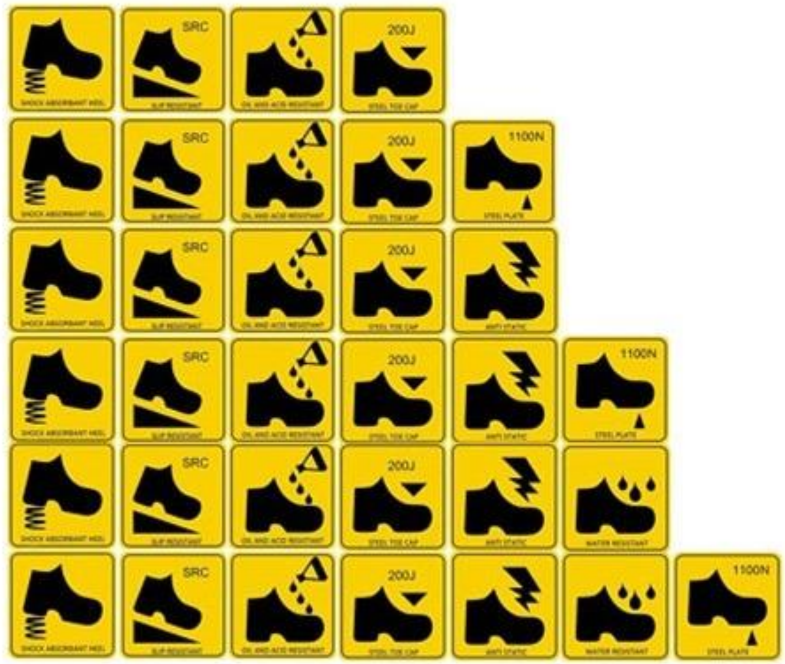



**Figure 9.** Types of Foot Protection

Protective work shoes must be manufactured in accordance with Turkish and European standards and selected based on the specific requirements of the job. Relevant standards are as follows:

- TS EN ISO 13832-1-2-3: Standard for footwear protecting against chemicals.
- TS EN ISO 20345: Safety footwear standard designed for protection against injuries.
- TS EN ISO 20346: Protective footwear standard with a lower safety requirement than 20345.
- TS EN ISO 20347: Standard for occupational footwear not requiring toe protection.
- TS EN ISO 20349-1: Protective footwear standard for workers in foundries.
- TS EN ISO 20349-2: Protective footwear standard for workers engaged in welding and related processes.
- TS EN 50321: Electrical insulating footwear standard for workers operating under voltage. (T.C. Ministry of Labour and Social Security, 2022)

## 3. SECTORAL WORK ACCIDENT CASES CAUSED BY THE ABSENCE OF PERSONAL PROTECTIVE EQUIPMENT (PPE)

### 3.1. Case 1

A survey was conducted with 1,000 workers employed in six ceramic factories in Bozüyük district of Eskişehir, Türkiye. After eliminating invalid responses, 551 valid questionnaires were evaluated using the Chi-Square test in a statistical software package.

It was observed that employers had provided appropriate PPE for the type of work, but workers' use of PPE was insufficient. According to the survey results, workers stated that PPE hindered their movement, caused physical discomfort, or was of poor quality — leading them to avoid using it.

This data indicates that PPE should be designed in compliance with standards to ensure consistent use. It was also concluded that workers need to receive adequate training on PPE use. Periodic inspections and audits conducted by employers and occupational safety specialists are considered crucial to preventing work accidents (Açıkalın, 113177).

### 3.2. Case 2

On February 19, 1984, a worker named T.D. employed at an industrial textile factory suffered an eye injury resulting in partial vision loss. The accident occurred when a hook, rotating at 4,000 rpm on a yarn twisting machine, was ejected and struck the worker's eye. T.D. was determined to have a 24.2% disability.

T.D. filed a compensation lawsuit (material and moral damages). The Supreme Court confirmed that the employer bore 20% fault and 80% inevitability. Investigations revealed that although safety goggles and occupational safety training had been provided to employees, including T.D., their use was not enforced during operation.

Under Article 43 of the Turkish Code of Obligations (then in effect), the court ruled T.D. 27% at fault, and the employer 73% at fault. The Kocaeli 1st Labour Court finalized the ruling, and T.D. received compensation and other benefits.

Several years later, T.D.'s visual impairment worsened, increasing his disability rate to 39%. Based on this updated evaluation, he earned the right to file a second compensation claim for the additional 14.8% impairment. Despite the employer's objections, the court again ruled in favor of T.D., recognizing that the increased disability was a direct consequence of the initial work accident, and awarded him additional compensation with legal interest (Çalışma Ortamı Journal, 2025).

### 3.3. Case 3

Between April 2022 and January 2023, a survey regarding workplace accidents was conducted with hospital personnel working at Kırklareli Research Hospital. After eliminating invalid responses, a total of 405 valid questionnaires were evaluated.

The surveys were conducted face-to-face with participants at random time intervals, including both working and non-working hours on weekdays and weekends. Prior to the survey, informed consent was obtained from all participants. The survey form consisted of two sections and 23 questions, focusing on personal characteristics and experiences related to occupational accidents.

As a result of the study, it was determined that:

- Two out of every three employees encountered potential accident risks,
- One in two experienced at least one occupational accident throughout their career,
- And one in four experienced a work accident within the past year.

The most frequent accident risks involved sharp or penetrating objects, with the most common injuries occurring on the forearm, wrist, inner wrist, hand, and palm. The primary causes of these incidents were identified as distraction, fatigue, and lack of attention. Additionally, a lack of occupational health and safety (OHS) training and insufficient awareness of personal protective equipment (PPE) were reported.

It was recommended that periodic risk assessments be carried out by the employer and safety specialists, and that identified risks be addressed with preventive measures. To minimize such risks, all hospital employees should be provided with appropriate PPE and mandatory OHS training. It is expected that the number of workplace accidents will decrease significantly following the implementation of these measures (Pancar, 2024).

### 3.4. Case 4

A survey on the use of personal protective equipment (PPE) was conducted among construction workers in the province of Trabzon, Türkiye. The survey took place between January and February 2015, covering 398 construction workers randomly selected from 30 different construction sites across the region. The collected data was analyzed using a statistical software package.

According to the survey:

- 95.98% of the participants believed that PPE provides effective protection against work accidents.

- However, field observations revealed a significant discrepancy between these beliefs and actual practices — many workers did not use the available PPE, or used it improperly or carelessly.

When asked who would be at fault if an accident occurred despite wearing PPE:

- 92.21% of respondents blamed themselves,
- 3.52% blamed the employer,
- 2.76% held the site supervisor responsible,
- And 1.51% blamed the OHS specialist.

However, according to current Turkish regulations, in the event of an occupational accident, primary responsibility lies with the employer, followed by the project manager, health and safety coordinator, and OHS expert, respectively. Employees are considered to have the least responsibility.

The study also revealed that most workers across these 30 construction sites had not received sufficient training and had not been adequately informed about PPE use (Atasoy, 2025).

**Conclusion**

The use of personal protective equipment (PPE) within the scope of occupational health and safety plays a vital role in preventing work-related accidents and occupational diseases. Research and case studies indicate that while employers are responsible for providing PPE, the effective reduction of workplace injuries significantly depends on proper and consistent use by employees. The effectiveness of PPE does not solely rely on its availability, but also on ensuring its suitability for specific working conditions, compliance with established safety standards, regular maintenance, and correct usage. Survey results and field observations reveal that employee reluctance to use PPE is often linked to discomfort, lack of proper training, and insufficient supervision.

In this regard, employers must go beyond fulfilling legal obligations and actively engage in raising awareness among employees about the importance of PPE through continuous training and regular inspections. In high-risk sectors in particular, the use of PPE affects not only individual health but also corporate productivity and operational continuity. In conclusion, the effective, appropriate, and consistent use of personal protective equipment is an indispensable element in building a sustainable occupational safety culture.

**Recommendations**

To effectively prevent occupational accidents, employers should not limit their responsibilities to merely providing personal protective equipment (PPE); they must also offer regular and hands-on training for employees. These trainings should go beyond theoretical knowledge and be supported with field applications and case analyses. Furthermore, PPE should be ergonomically designed based on employee needs and feedback to encourage consistent usage. Establishing feedback mechanisms to quickly identify and address user complaints or difficulties will enhance overall compliance and effectiveness.

At the institutional level, PPE usage should be systematically monitored, with regular reports on usage frequency and correct application. Based on this data, targeted improvements can be implemented in departments where deficiencies are detected. Moreover, sector-specific national awareness campaigns and public service announcements should be launched to raise awareness of the importance of PPE. Establishing a strong safety culture at the workplace requires more than regulatory enforcement; it depends on active employee participation and management's firm commitment to occupational health and safety principles.

**References**


Açıkalın, C. (2025). *İş yerinde çalışan eğitimi ve kişisel koruyucu donanım kullanımı*. Eskişehir Osmangazi Üniversitesi, İ.İ.B.F., Sosyal Bilimler Dergisi, 9(1). DergiPark. https://dergipark.org.tr

Atasoy, M. (2025). İnşaat sektöründe çalışan işçilerin kişisel koruyucu donanım kullanım sıklığının belirlenmesi; Trabzon ölçeğinde. *5. İşçi Sağlığı ve İş Güvenliği Sempozyumu*. https://eski.imo.org.tr/resimler/ekutuphane/pdf/17614_44_16.pdf

Beşer, F. (2012). *İş sağlığı ve güvenliği kanunu*. Mevzuat Bilgi Sistemi. Resmî Gazete Tarihi: 30.06.2012, Sayı: 28339.

BİMA Uluslararası Pazarlama Danışmanlık İmalat San. ve Tic. Ltd. Şti. (2025, Ekim 16). *İş güvenliğinde maske ve solunum koruyucuların önemi*. https://bima.com.tr/tr/is-guvenliginde-maske-ve-solunum-koruyucularin-onemi

Çalışma Ortamı Dergisi. (2025, Ekim 15). İşyerinde göz yaralanmalarının sonucu kimleri etkiler. https://calismaortami.fisek.org.tr/icerik/isyerinde-goz-yaralanmalarinin-sonucu-kimleri-etkiler

ÇSGB. (2022). *Ayak ve bacak koruyucu donanımlar*. https://isg.marmara.edu.tr/dosya/isg/organizasyon%20%C5%9Femas%C4%B1/ayak-ve-bacak-koruyucular-may%C4%B1s-2022%20(1).pdf

ÇSGB. (2025). *Baş koruyucu donanımlar*. https://kkdportal.csgb.gov.tr/kkd-urun-kategorileri/bas-koruyucu-donanimlar/

İSBU. (2025, Ekim 14). *Vücut koruyucu kıyafet standartları nelerdir*. https://www.isbu.com.tr/blog/icerik/vucut-koruyucu-kiyafet-standartlari-nelerdir

Kartal, Ö. (2016). *İş yerinde çalışan eğitimi ve kişisel koruyucu donanım kullanımı* [Yüksek lisans tezi, İstanbul Yüzyıl Üniversitesi].

Lindström. (2025, Ekim 14). En340 nedir ve hangi iş kıyafetleri için geçerlidir? https://lindstromgroup.com/tr/makaleler/en-340-nedir-ve-hangi-is-kiyafetleri-icin-gecerlidir/

Pancar, N. (2024). Hastane çalışanlarında iş kazaları epidemiyolojisi ve etkileyen faktörler. *DergiPark Akademi*, 33(3), 229–242.

Yılmaz, H. D. (2025). *İş sağlığı ve iş güvenliği amacıyla kullanılan tekstil ve konfeksiyon ürünü seçilmiş kişisel koruyucu donanımlar ve standartları* [Yüksek lisans tezi, Çukurova Üniversitesi].