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Waste Assessment of 1.275 MW_P PV Plant: Case of Northern Cyprus

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Abstract

PV technologies gained significant importance during the last 2 decades by providing clean and renewable electricity. However, PV panels complete their operational life in 25-30 years and transform into hazardous waste for both human health and environment. Management of PV Waste is an important environmental issue which requires a detailed inventory of the PV Waste. In this study, the PV Waste inventory of 1.275 MW_P PV Plant installed in Serhatköy Region of Northern Cyprus, on May 2011, is investigated. Results showed that, this plant will complete its operational lifetime in 13-18 years and generate the first bulk PV Waste in Northern Cyprus. Inventory analysis of the Serhatköy PV Plant revealed that 63476 kg of glass,16807 kg of aluminum, 9230 kg of steel, 6640 kg of EVA, 807 kg of silicon, and 746 kg of copper can be recycled and recovered. Also, this study revealed that Northern Cyprus can catch the PV Waste Management targets of the European Union with a down-cycling PV Waste Strategy.

Keywords: PV Plant, PV Module, Waste Management, Material Recovery.

1.275 MW_P Güneş Santralinin Atık Değerlendirilmesi: Kuzey Kıbrıs Örneği

Öz

Son 20 yılda fotovoltaik teknolojileri temiz ve yenilenebilir elekrik ürettikleri için belirgin bir önem kazanmıştır.. Bununla birlikte, güneş panellerinin operasyonel ömürlerinin yaklaşık olarak 25-30 yıl içinde tamamlamaktadır. Operasyonel ömrünü tamamlamış olan güneş panelleri, içerikleri dolayısı ile hem insan sağlığına hem de çevreye zararlı olabilmektedir. Operasyonel ömrünü tamamlayarak, elektronik atığa dönüşmüş güneş panellerinin ne şekilde depolanacağı veya yönetileceğine karar verilebilmesi için, bu atıkların içeriğindeki madde çeşitlerinin ve miktarlarının belirlenmesi gerekmektedir. Bu çalışmada, Kuzey Kıbrıs'ın Serhatköy bölgesinde 2011 yılında kurulan 1.275 MW_P'lık güneş santralinin, operasyonel ömrünü tamamladığında ortaya çıkacak olan atık tür ve miktarları araştırılmıştır. Bu çalışma ile bu santralin operasyonel ömrünü 13-18 yıl içinde tamamlayacağı ve Kuzey Kıbrıs'ın ilk toplu fotovoltaik panel atıklarını oluşturacağı gösterilmiştir. Sonuçlar, santral ömrünü tamamladığında, uygun bir geri dönüşüm yöntemi ile 63476 kg cam,16807 kg aluminyum, 9230 kg çelik, 6640 kg EVA, 807 kg silikon, ve 746 kg bakırın geri dönüştürülebileceğini göstermektedir. Bunun yanında, bu çalışma ile Kuzey Kıbrıs'ta kurulacak temel geridönüşüm sistemleri ile Avrupa Birliği hedeflerinin yakalanabileceğini gösterilmiştir.

Anahtar Kelimeler: Güneş Santrali, Fotovoltaik Panel, Atık Yönetimi, Geridönüşüm.

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1. Introduction

Photovoltaic (PV) technologies gained significant importance for meeting the rising electricity need of the world. PV technologies provide clean electricity, using solar energy, which is abundant and predictable by measuring solar irradiation reaching Earth's surface (Phinikarides et al., 2014). According to, Snapshot of Global PV Markets 2021, report of International Energy Agency(IEA), the cumulative installed capacity for PV at the end of 2020 reached at least 760.4 GWdc (Masson, 2021). There exist different kinds of PV technologies for the generation of electricity. PV panels are generally classified as; Crystalline silicon (monocrystalline or multi-crystalline); thin film and concentrator photovoltaics with emerging technologies (Xu et al., 2018).

PV technology contributes to preventing environmental problems associated with the consumption of fossil fuels. However, it must be pointed out that, each technology has an operational lifetime and it is converted to waste, at the end of this lifetime. The lifetime of PV modules is commonly considered to be 25-30 years. However, several factors like climatic conditions or technological improvements may result in the earlier replacement of the modules (Tan et al, 2022). PV Technologies, simply PV panels provide environmentally friendly electricity generation and perform zero CO_2 emission during operational life. Nevertheless, these panels turn into electronic waste at the end of their operational life and have the potential to create environmental problems (Qi and Zhang, 2017). The major ingredients of solar cells in PV panels can be listed as; Lead (Pb), tin (Sn), cadmium (Cd), silicon (Si), and Copper (Cu) (Mahmoudi et al., 2019; Weckend and Wade~~,~~ 2016). Disposal of these listed elements to open landfill should be prevented since they have hazardous effects on both human health and the ecosystem (Abigail et al.,2022; Deng et al.,2019). Even more, it must be pointed out that; glass, EVA (ethylene-vinyl acetate), and aluminum are the major components of PV modules (Mahmoudi et al., 2019; Weckend and Wade~~,~~ 2016), which all are recyclable substances, and disposal of these substances results in the loss of raw material. The waste management and disposal of PV modules require well planned and achievable strategy; since modules contain both recyclable substances and hazardous substances.

According to statistics collected by, Mahmoudi et al. (2019) (Mahmoudi et al.,2019), crystalline Silicone PV panels dominate the PV market since 1980 and will continue to be dominating until 2030 (Paiano, 2015; Weckend and Wade, 2016). Therefore, the global PV waste management strategies of countries should initially concentrate on recycling silicon-based panels, where waste management of other types of PV panels should be planned as well.

Despite the fact that PV installations are rising exponentially with the promoting energy policies, countries like the United States, China, Japan, and India lack regulations for the disposal of PV modules (Wang et al., 2022). Nevertheless, European Union revised the waste electrical and electronic equipment (WEEE) directive and added the PV components as disposed electronic devices (Xu et al.,2018). According to the revised WEEE directive (2012/19/EU), from 2018 and beyond, it is targeted to recover 85% of PV panels and prepare 80% for reuse and recycling (Weckend and Wade, 2016).

PV installations and managing PV waste are especially important for the countries in Mediterranean Region, which has high solar energy potential. Northern Cyprus is a small island state, with a total surface area of 3355 km^2 in the Mediterranean region, and has huge potential for meeting electricity demand with solar energy. Although the region mainly meets the electricity demand by combusting fossil fuels, there exists a PV plant, located in the Serhatköy region with a capacity of 1.275 MW_P.

Generating a PV waste management strategy has significant importance for states like Northern Cyprus which has limited resources. A well-planned PV waste management strategy requires inventory analysis of the possibly generated waste. In this study, the amount of waste generated by the disposal of 1.275 MW_P, Serhatköy PV Plant, is analyzed with the aim of contributing to the possible PV waste management strategy of Northern Cyprus. The analysis considers only the waste produced by PV Panels whereas waste generated by other components like inverters or transformers is not considered. For that purpose, the composition and amount of PV panels used in the Serhatköy PV Plant is evaluated according to early loss and regular loss scenarios, by using Weibull Distribution. The possibility of loss for each substance in PV Panels is investigated according to each scenario. In this study, also, the possible way of catching targets of WEEE is for Northern Cyprus investigated.

2. Materials and Methods

The Serhatköy PV Plant is connected on grid on May 2011. The plant includes a total number of 6192 c-Si modules type KPV205 PE with 206 Wp output each, manufactured by the Austrian KIOTO Photovoltaics, fixed tilt on mounting structures, 86 inverters, the AC connection, MV transformers, metering and control interfaces with the grid (Maltini and Minder, 2015). Figure 1 shows the site view of Serhatköy PV Plant. The plant layout surface is approximately 25,000 m^2. The panel and module-cell specifications of the panels installed in Serhatköy PV Plant is shown in Table 1.

The material composition of c-Si panels is given by Mahmoudi et al. (2019) and shown in Table 2. Material inventory of Serhatköy PV Plant, which shows the amount of, precious metals(Ag), base and special metals (Al, Cu, Ni, Ti, Sn, Zn), hazardous metals (Pb), Critical Substances(Mg), Other Metals (Si, Steel) and other materials (glass and EVA) is evaluated by using Table 2.

Figure 1. Site view of Serhatköy PV Plant (Maltini and Minder, 2015)

The estimation of PV Waste amounts is generally investigated by two scenarios, which are Regular Loss and Early Loss. In regular loss scenario, it is assumed that the panel has a lifetime of 30 years, whereas early loss considers the failures before the 30-year lifetime span (Weckend and Wade, 2016). Early Loss and Regular Loss scenarios are generally modelled by using Weibull Function (Mahmoudi et al., 2019), given below;

$$P(t) = 1 - e^{-(t/T)^{\gamma}} \tag{1}$$

$P(t)$ is the Weibull Function which shows the probability of loss in t years in panel lifetime T, which is 30 years. γ is the shape factor of the Weibull function and it is 2.4928 for the early loss scenario and 5.3759 for the regular loss scenario (Weckend and Wade, 2016; Mahmoudi et al., 2019). Figure 2., shows how the probability of loss according to early loss and regular loss scenarios.

Table 1. Module-Cell Specifications of Serhatköy PV plant (Maltini and Minder,2015).

Module and Cell Specifications	
Quantity of Modules	6192
Supplier	KIOTO KPV 205 PE
Characteristics of Module	54 multicrystalline cells (156mm × 156mm)
Cells	6” multi-crystalline
Umpp	25.98 V
Impp	7.93 A
Uoc	32.57 V
Isc	8.44 A
Surface per kWp	7.26 m^2
Power	205(Wp)
Area	1.49 m^2
Weight	16.50 kg
Average Weight	0.08(kg/Wp)

Table 2. Material composition of c-Si PV Panels (Mahmoudi et al.,2019).

Substance	Composition Percentage (%)
Glass	65.4
Al	16.5
Steel	9.51
EVA	6.5
Si	0.791
Cu	0.731
Mg	0.52
Ag	0.0577
Pb	0.00467
Ni	0.00106
Ti	0.0000052
Sn	0.0000586
Zn	0.00000781

According to, Weibull distribution, there is a significant difference between early loss and regular loss in the first 20 years of installation. However, this difference is started to reduce after the 20^{th} year of installation and the probability of loss becomes the same at the 30^{th} year of installation, which is the operational lifetime of the PV Panels.

In this study, cumulative mass of the Glass, Al, Steel, EVA, Si, Cu in composition of c-Si Panels is calculated in kg, by using Equation (2), as given below:

$$M_{substance} = CP_{Substance} \times m_{PV} \times N_{pv} \quad (2)$$

$M_{substance}$ represents the cumulative mass of each substance in composition of c-Si PV Panel (Glass, Al, Steel, EVA, Si, Cu). $CP_{Substance}$ is the composition percentage of the substance in PV Panel given by Mahmoudi et al. (2019) and listed in Table 2. m_{PV} and N_{pv} are the mass of single PV panel and number of PV Panels in Serhatköy PV Plant respectively, given in Table 1. The cumulative mass of each substance obtained from Equation (2), is multiplied by the Weibull Function, for calculating the probable amount of generated waste, for both early loss and regular loss probabilities in years.

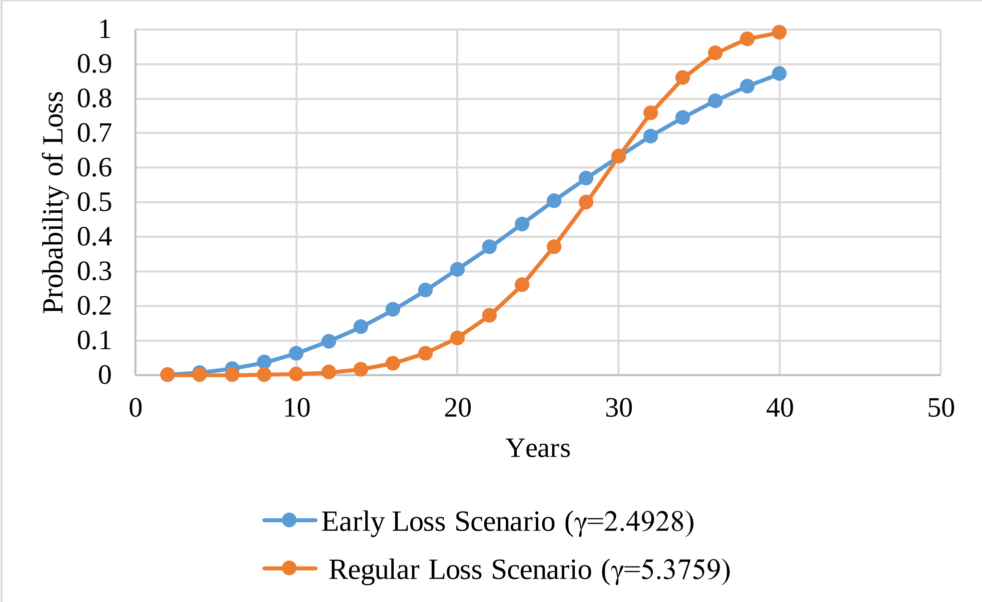

Figure 2. Probability of loss according to Weibull distribution with Early Loss and Regular loss scenarios.

Almost all substances, Precious Metals, Base and Special Metals, Hazardous Metals, Critical Substances, Other Metals and Other Materials, in the composition of PV Panels are recyclable materials and their recovery yields are given in Table 3.

Table 3. Recovery yield of substances included in the composition of c-Si Panels.

Substance	Recovery Yield(%)	Source
Ag	95	Mahmoudi et al., 2019
Al	99.7	Mahmoudi et al., 2019
Cu	100	Mahmoudi et al., 2019
Ni	41	Mahmoudi et al., 2019
Ti	52	Mahmoudi et al., 2019
Sn	32	Mahmoudi et al., 2019
Zn	27	Mahmoudi et al., 2019
Pb	96	Mahmoudi et al., 2019
Mg	33	Mahmoudi et al., 2019
Si	99.9	Mahmoudi et al., 2019
Steel	95	Weckend and Wade, 2016
EVA	100	Weckend and Wade, 2016
Glass	95	Weckend and Wade, 2016

The potential amount of substance (Glass, Al, Steel, EVA, Si, Cu), which can be recovered by recycling PV Panels installed in the Serhatköy PV Plant, is calculated by using Equation (3);

$$M_{RC} = M_{substance} \times RY \tag{3}$$

M_{RC} is the mass of the substance (Glass, Al, Steel, EVA, Si, Cu) obtained from the recovery. $M_{substance}$ is the cumulative mass of each substance (Glass, Al, Steel, EVA, Si, Cu) , obtained from Equation (2), and RY is the recovery yield of the associated substance shown in Table 3.

3. Findings and Discussion

Figure 3 shows the material inventory of the Serhatköy PV Plant obtained from Equation (2). Results showed that the main contributors of PV Panel waste will be Glass, Aluminium, Steel, and EVA, at the end of the operational life of the panels in the Serhatköy PV Plant. Also, the contribution of Silicon and Copper to generated waste is more significant compared to Mg, Ag, Pb, Ni, Ti, Sn, and Zn.

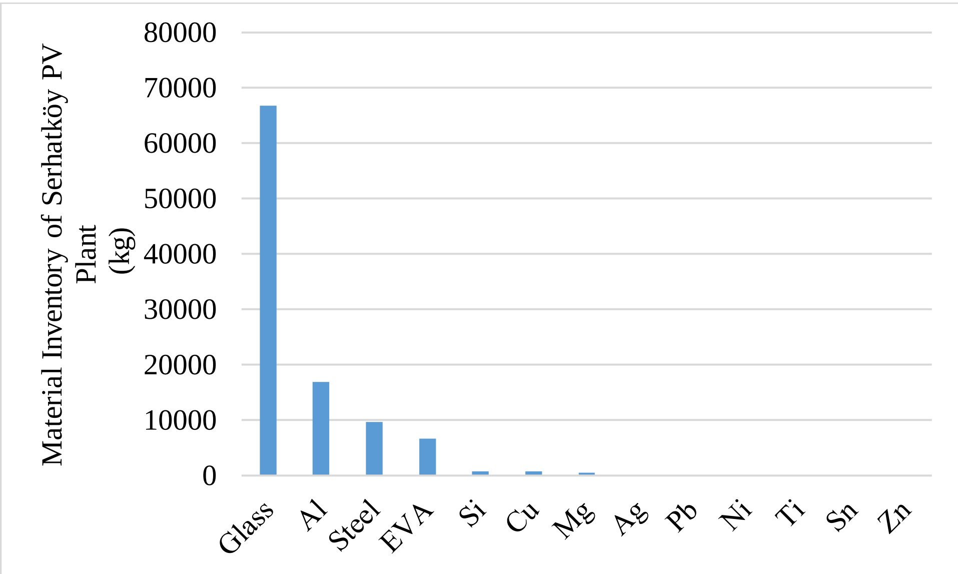

Figure 3. Material inventory of Serhatköy PV Plant

Results showed that; 66817 kg of glass will be disposed of at the end of the operational life of the PV Plant. However; there exists a rising possibility of loss in glass, after 2030, according to Weibull distribution of both early loss and regular loss scenarios as shown in Figure 4. The recovery rate of glass is 95% as given in Table 3 (Mahmoudi et al., 2019). The recovery and reuse of glass will contribute to saving natural resources, sand, and soda ash (Ferdous et al., 2021). In addition, one ton of recycled glass saves 0.12 barrels of oil (19 litres), 42 Kwh of energy, 3.4 kg of air pollutants from being released, and 1.5 cubic meters of landfill space (LBRE, 2020). Also, Cerchier et al. (2021) showed that; PV glass can be used for building materials production and sustainable mortar.

The material inventory of the Serhatköy PV plant showed that; approximately 16,857 kg of aluminium will be sent to landfills with disposal of Serhatköy PV Plant. Figure 5 shows the early loss and regular loss in Aluminium according to Weibull Function. Similar to the, glass the possibility of loss in aluminium also rises significantly after 2030. Approximately 6232 kg and 2900 kg of aluminium is expected to be sent to landfills according to early and regular loss scenarios respectively. Aluminium is mainly used in frames of the modules with a high recovery yield of 99.7% (Mahmoudi et al.,2019). Recycling aluminium contained in c-Si panels has the highest economic benefit, at approximately \$2.7/m^{2}module (Deng et al., 2022). Also, Peng et al. (2019) showed that; recycled the life-cycle energy consumption and GHG emissions of recycled aluminium production is only 6.37% and 4.45% of the primary aluminium. Studies showed that recycling these frames contributes to reducing the life-cycle global-warming potential (kg CO2-eq) of PV modules by 12% (Deng et al., 2022, Jia et al., 2020).

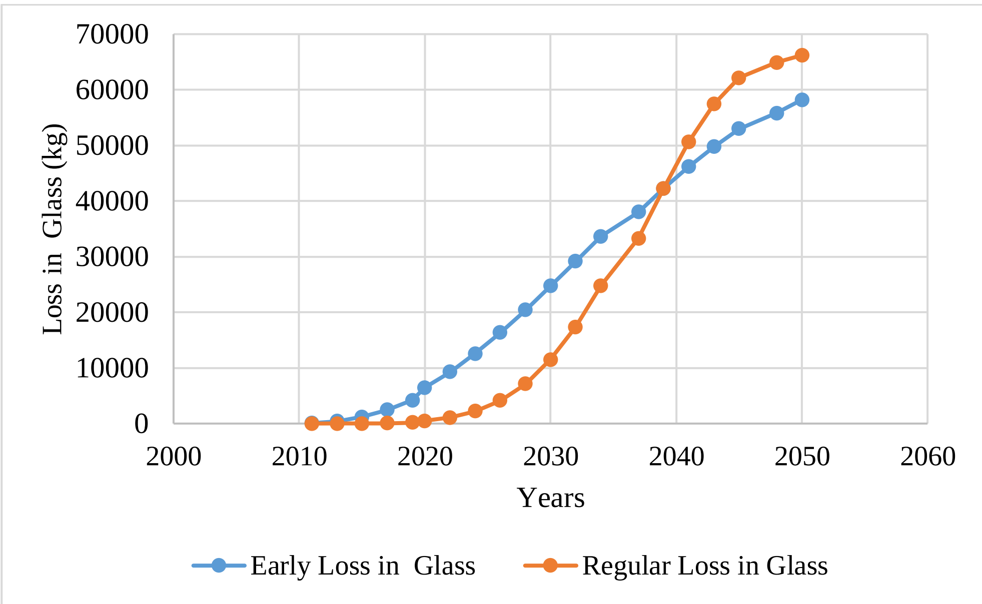

Figure 4. Loss in Glass according to early loss and regular loss scenarios.

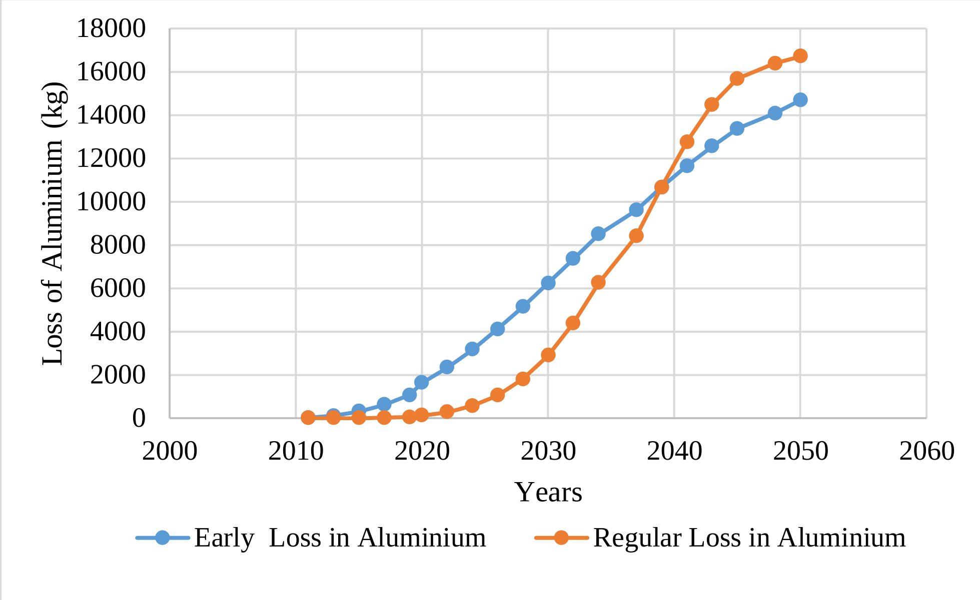

Figure 5. Loss in Aluminium according to early loss and regular loss scenarios.

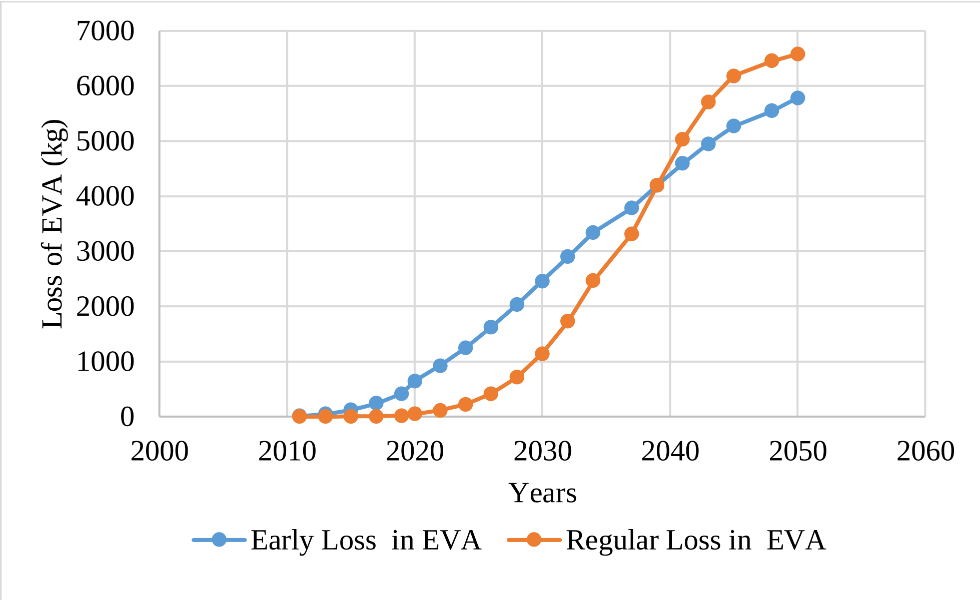

Figure 6. Loss in EVA according to early loss and regular loss scenarios.

EVA (ethylene-vinyl acetate) is used as encapsulating material for the photovoltaic module and accounts for 6.5% of the total panel weight (Mahmoudi et al.,2019). In particular, EVA is a co-polymer plastic material of ethylene and vinyl acetate and is used to assemble PV panels. The removal of the EVA is the first step for material recovery of end-of-life PV modules (Fiandra et.al., 2019). Material inventory of Serhatköy PV Plant showed that, 6640 kg of EVA will be demolished within 2036-2041. However, early loss and regular loss scenarios of EVA, shown in Figure 6, show that the probability of regular loss significantly rises after 2030 similar to glass and aluminium. The recovery rate of EVA is 100% (Weckend and Wade, 2016). There exist thermal and chemical methods for the removal of EVA. Chemical Methods are including dissolving EVA in chemical solvents or acids (Doi et al., 2001; Fiandra et.al., 2019 Kang et al., 2012; Kim and Lee, 2012) where thermal methods decompose EVA with pyrolysis (Fiandra et.al., 2019; Dias et al., 2016; Dias et al., 2017).

Silicon is one of the most important substances which can be recycled in PV Panels. Silicon production is an intensive energy-consuming process (Xu et al., 2018), where the energy and cost needed to recover silicon from recycled solar panels are equivalent to only one-third of those of manufacturing silicon directly (Choi & Fthenakis ,2010, Xu et al., 2018). Material inventory of the Serhatköy PV Plant showed that approximately 808 kg of silicon will be disposed of when the plant completes its operational life. Nevertheless, by 2030, 100 kg-300 kg of silicon is estimated to be lost according to regular loss and early loss scenarios respectively as shown in Figure 7.

Figure 8 shows the loss in Copper according to early loss and regular loss scenarios. Copper is one of the highly generated wastes from the disposal of PV Panels, the disposal of a 1.275 MW_P PV Plant will result in the disposal of approximately 746 kg of Copper. As given in Table 3, the recovery yield of Copper is 100%. However, the removal of Copper requires the use of chemicals and exhaustive systems during the separation and purification process (Sah et al., 2022).

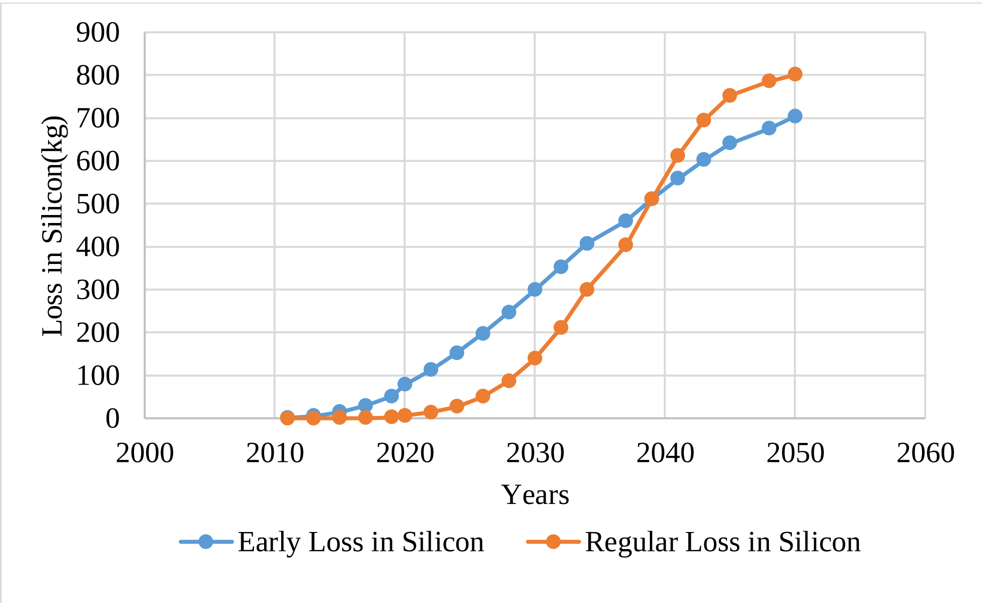

Figure 7. Loss in Silicon according to early loss and regular loss scenarios.

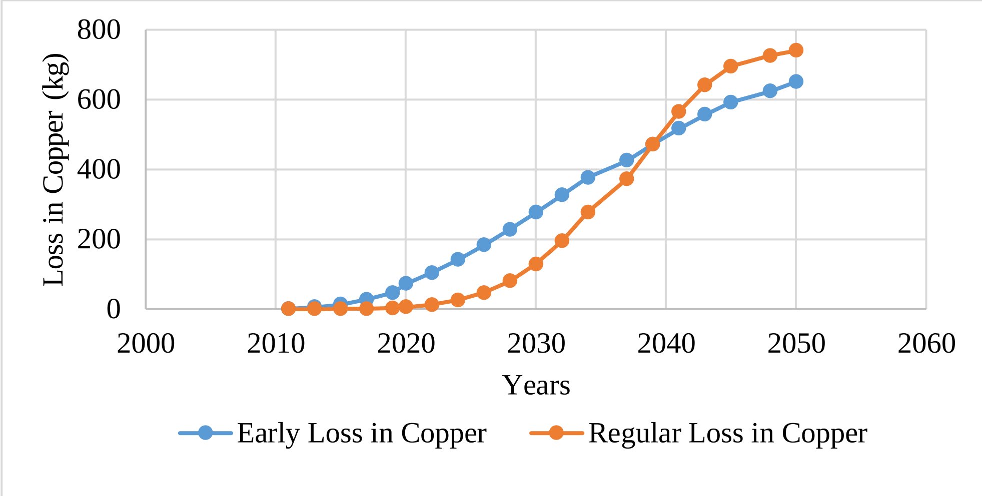

Figure 8. Loss in Copper according to early loss and regular loss scenarios.

Similar to Aluminium, steel is one of the metals used in frames (Komoto and Lee, 2018) of the PV modules and have a high potential, 95%, for recycling. According to the composition given by, Mahmoudi et al. (2019), it is estimated that almost 9716 kg of steel will be demolished in the 2050 from Serhatköy PV Plant as shown in Figure 9.

Figure 10 shows, the potential amount of substances that can be obtained from the recovery of the PV Panels installed in the Serhatköy PV Plant according to Equation (3). According to Figure 10, 63476 kg of glass, 16807 kg of aluminium, 9230kg of steel, 6640 kg of EVA, 807 kg of Silicon, and 746 kg of Copper can be recycled and recovered from Serhatköy PV Plant.

PV waste recycling and disposal is a challenging topic and recycling methods require chemical, thermal and mechanical treatments (Xu et al.,2018). Recycling technologies can be divided into two categories as; upcycling (high-valued recycling) and down-cycling (low-valued recycling) (Deng et al.,2019). Most companies in Europe use the down-cycling method for the disposal of PV waste (Wang et al.,2022). The down-cycling process starts with the removal of the Aluminium frame and the module is shredded which is followed by a manual and mechanical extraction process for the recycling of glass and aluminium (Wambach,2017). In addition, the ferrous material can be sent to a recycler where the remaining silicon, metal, plastic, and glasses which cannot be further separated by shredder are sent to a landfill.

Nevertheless, the upcycling technologies provide recovery of high-quality glass, silicon wafers, and also valuable metals with module delamination (Deng et al.,2019; Wang et al.,2022). Upcycling technologies are more cost and energy consuming, also more complex, compared to down-cycling technologies, because of the use of more energy and chemicals (Deng et al., 2019; Wambach, 2017; Duflou et. al. 2018).

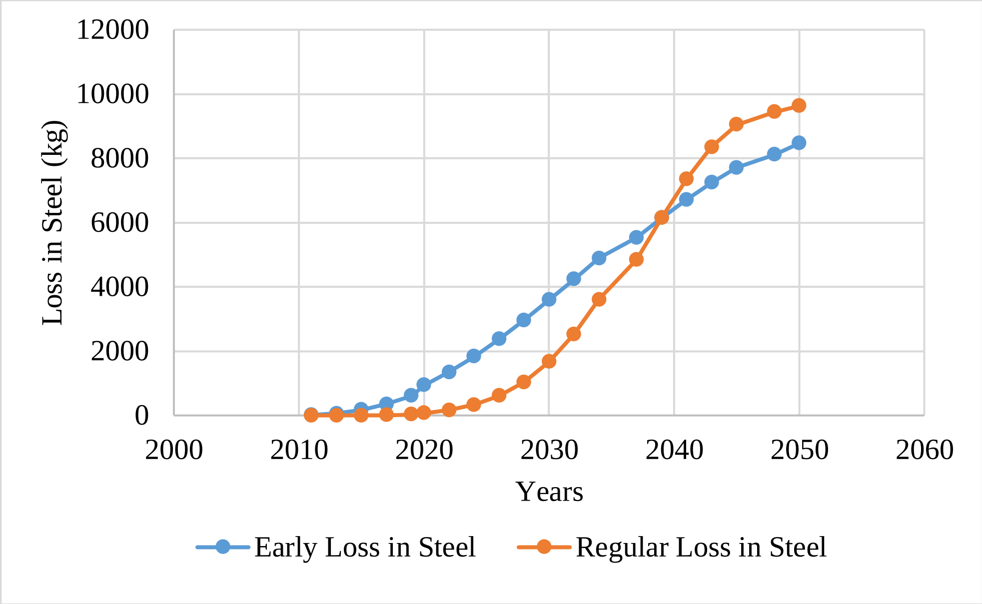

Figure 9. Loss in Steel according to early and regular loss scenarios.

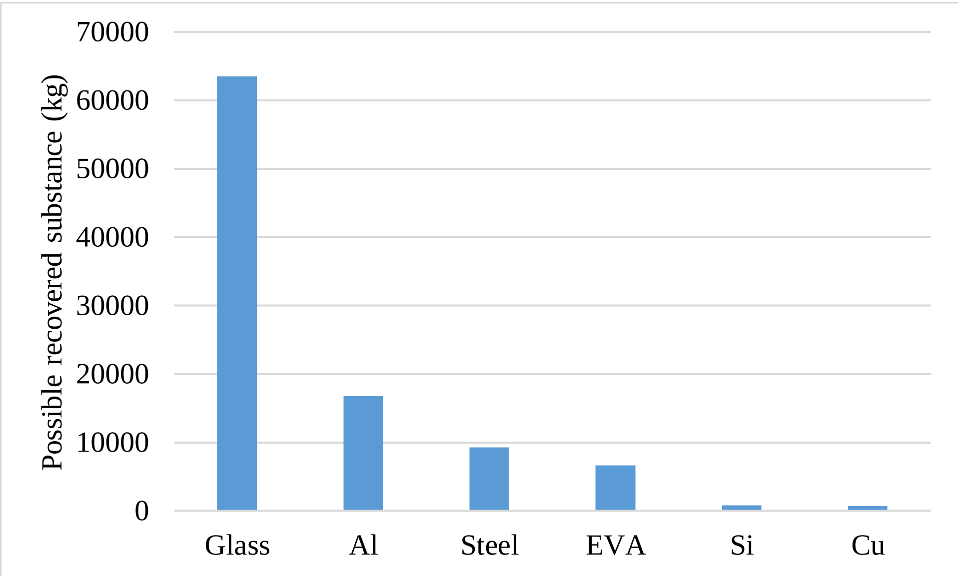

Figure 10. Materials obtained from the recovery of C-Si PV Panels.

In the meantime, Huang et al. (2017), showed that recovery of a 60-cell Si module can generate a revenue stream of \$16–17, and the revenue can cover the recycling cost and keep up a profitable recycling business without any government support.

Northern Cyprus is a small island state, with limited resources and industry. PV Plants are promising systems for producing electricity for states like Northern Cyprus, which suffers from lack of resources. However, this study showed that the disposal of a $1MW_P$ PV Plant can be turned into a challenging issue at the end of its operational life. This study showed that the main contributors to PV waste of the Serhatköy PV Plant will be glass and aluminium. Although the waste of a $1MW_P$, PV plant can be handled by landfilling, rooftop and commercial PV installations should also be investigated for an achievable waste management strategy. According to statistics published by the Cyprus Turkish Electricity Authority (KIB-TEK), currently, Northern Cyprus can 5.56% of total generated electricity, from PV, with the contribution of rooftop and commercial applications in 2022, where PV Panels could only have contributed 0.11% of total electricity generation in 2018 with Serhatköy PV Plant (KIBTEK, 2022).

The PV installation statistics showed that Northern Cyprus needs urgent, sustainable, and achievable targets for the management of waste generated from PV Panels. The calculations based on Serhatköy PV Plant showed that the target stated by the WEEE of European Union can be cached by a down cycling strategy and almost 80%-85% of the generated PV waste can be recovered. Nonetheless, a detailed inventory analysis of rooftop and commercial installations should be conducted for constructing the most profitable management plan for PV waste in Northern Cyprus.

4. Conclusions and Recommendations

Serhatköy PV Plant, which operates since 2011, will complete its operational life in 2036-2041. It will be the first bulk PV waste of Northern Cyprus which is required to handle in 14-18 years. The early loss and regular loss scenarios based on Weibull distribution showed that the probability of loss after 2030 will rise significantly. Also, the climatic conditions in Northern Cyprus may result in an earlier disposal of the PV plant. This study showed that; a sustainable and achievable PV waste management strategy is urgent for Northern Cyprus. The PV waste management strategy of Serhatköy PV Plant has significant importance in that, it will determine the future of PV waste in Northern Cyprus. Results obtained from this study state that the target of the European Union with WEEE is achievable with a down-cycling plant. Further analysis of PV waste in Northern Cyprus, by considering whole PV installations, will indicate the most profitable way of PV waste management. Also, such a plant can contribute to the economy of the country by providing new job opportunities and investment opportunities.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

References

Abigail, H.L.D., Tariq, R. Mekaoui, A. E., Bassam, A., Lille, M. V. D. Ricalde, L. J., and Riech, I. (2022) Does recycling solar panels make this renewable resource sustainable? Evidence supported by environmental, economic, and social dimensions, *Sustainable Cities and Society*, 77,103539.

Cerchier P., Brunelli K., Pezzato L., Audoin C., Rakotoniaina J.P., Sessa T., Tammaro M., Sabia G., Attanasio A., Forte C., Nisi A., Suitner H., and Dabalà M., (2021) Innovative Recycling of End of Life Silicon PV Panels: RESIELP, *Detrius*, 16, 41-47.

Choi, J.K., and Fthenakis, V., (2010) Design and optimization of photovoltaics recycling infrastructure, *Environmental Science and Technology*, 44, 8678–8683.

Cyprus Turkish Electricity Authority (KIB-TEK), İstatistikler – KIBRIS TÜRK ELEKTRİK KURUMU (kibtek.com), last accessed on 04.04.2023

Deng, R., Chang, N.L., Ouyang, Z., and Chong, C.M. A techno-economic review of silicon photovoltaic module recycling, (2019) *Renewable and Sustainable Energy Reviews*, 109, 532–550.

Deng R., Zhuo Y., and Shen Y. , Recent progress in silicon photovoltaic module recycling processes (2022) *Resources, Conservation and Recycling*, 187, 106612.

Dias, P.R., Benevit, M.G., and Veit, H.M., (2016) Photovoltaic solar panels of crystalline silicon: characterization and separation. *Waste Management& Research*, 34 (3), 235–245.

Dias, P., Javimczik, S., Benevit, M., and Veit, H., (2017) Recycling WEEE: polymer characterization and pyrolysis study for waste of crystalline silicon photovoltaic modules, *Waste Management*, 60, 716–722.

Doi, T., Tsuda, I., Unagida, H., Murata, A., Sakuta, K., and Kurokawa, K., (2001) Experimental study on PV module recycling with organic solvent method. *Solar Energy Materials and Solar Cells*, 67, 397–403.

Duflou J.R., Peeters J.R., Altamirano, D., Bracquene, E., and Dewulf W., (2018) Demanufacturing photovoltaic panels: Comparison of end-of-life treatment strategies for improved resource recovery, *CIRP Annals*, 67(1), 29-32.

Ferdous W., Manalo A., Siddique R., Mendis P., Zhugee Y., Wong H. S., Lokuge W., Aravinthan T., and Schubeli P., (2021) Recycling of landfill wastes (tyres, plastics and glass) in construction – A review on global waste generation, performance, application and future opportunities, *Resources, Conservation and Recycling*, 173, 105745.

Fiandra,V. , Sannino,L., Andreozzi,C., and Graditi, G. (2019) End-of-life of silicon PV panels: A sustainable materials recovery process, *Waste Management*, 84, 91-101.

Huang, W.H., Shin, W.J., Wang, L., Sun, W.C., and Tao, M., (2017) Strategy and technology to recycle wafer-silicon solar modules, *Solar Energy*, 144, 22-31

Jia,X. , Lv, F., Li, P., Wang, W. (2020)Life-cycle assessment of p-type multi-Si back surface field (BSF) solar module in China of 2019, (2020), *Solar Energy*, 196 ,207-216.

Kang, S., Yoo, S., Lee, J., Boo, B., Ryu, H., (2012) Experimental investigations for recycling of silicon and glass from waste photovoltaic modules, *Renewable Energy*, 47, 152–159.

Kim, Y., and Lee, J., (2012) Dissolution of ethylene vinyl acetate in crystalline silicon PV modules using ultrasonic irradiation and organic solvent, *Solar Energy Materials and Solar Cells*, 98, 317–322.

Komoto K., and Lee J-S., (2018) End-of-Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies, IEA PVPS Task12, Subtask 1, Recycling Report IEA-PVPS T12-10:2018.

LBRE 2020, Stanford Recycling: Land, Buildings & Real Estate, Peninsula Sanitary Service/Stanford Recycling, USA (2020), lbre.stanford.edu.

Mahmoudi, S.; Huda, N., and Behnia, M. (2019) Photovoltaic waste assessment: Forecasting and screening of emerging waste in Australia, *Resources, Conservation & Recycling*, 146, 192–205.

Maltini, F. and Minder, R. The Serhatköy photovoltaic power plant and the future of renewable energy on the Turkish Republic of Northern Cyprus (2015) In Eco-Friendly Innovation in Electricity Transmission and Distribution Networks, Woodhead Publishing: Sawston, UK, 377–402.

Masson G., (2021), Snapshot of Global PV Markets 2021, International Energy Agency(IEA), Report IEA-PVPS T1-39:2021

Qi, L., and Zhang,Y. , (2017) Effects of solar photovoltaic technology on the environment in China *Environmental Science and Pollution Research*, 24 22133–22142.

Paiano, A., (2015) Photovoltaic waste assessment in Italy. *Renewable and Sustainable Energy Reviews*, 41, 99-112.

Peng, T., Ou, X., Yan, X., and Wang, G. (2019) Life-cycle analysis of energy consumption and GHG emissions of aluminium production in China, *Energy Procedia*, 158 3937-3943

Phinikarides A., Kindyni N., Makrides G., and Georghiou, G.E., (2014) Review of photovoltaic degradation rate methodologies, *Renewable and Sustainable Energy Reviews*, 40, 143–152.

Sah, D.,Chitra, Kumar, S., (2022) Recovery and analysis of valuable materials from a discarded crystalline silicon solar module, *Solar Energy Materials and Solar Cells*, 246, 111908.

Tan, V., Dias, P.R., Chang, N., and Deng, R.(2022) Estimating the Lifetime of Solar Photovoltaic Modules in Australia. *Sustainability*, 14, 5336.

Wambach K., (2017) Life cycle inventory of current photovoltaic module recycling processes in Europe (2017), IEA PVPS Task12, Subtask 2, LCA Report IEA-PVPS T12-12:2017

Wang, X., Tian, X., Chen, X., Ren, L., and Geng, C., A review of end-of-life crystalline silicon solar photovoltaic panel recycling technology, (2022), *Solar Energy Materials and Solar Cells*, 248, 111976.

Weckend, S., Wade, A., and Heath, G., (2016) End-of-Life Management: Solar Photovoltaic Panels, IRENA AND IEA-PVPS.

Xu Y., Li J., Tan Q., Peters A.L., and Yang C., (2018) Global status of recycling waste solar panels: A review, *Waste Management*, 75, 450-458.