

PROFESSIONAL TRAINING REPORT

***Sathyabama Institute of Science and
Technology (Deemed to be University)***

***DEPARTMENT OF ELECTRICAL AND
ELECTRONICS ENGINEERING***

NAME : DINESH M

REG NO. : 39140013

VATIO®



Certificate OF INDUSTRY INTERNSHIP

This is to certify that

DINESH M

Studying **3rd Year, B.E, EEE** in **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY**

has successfully completed the Industry Internship Programme at VATIO Energy India Pvt Ltd, Chennai
through Online from 21st July to 05th August 2021 in the area of
"Solar Photovoltaic system & its Design Practices"

Best wishes from VATIO Energy for future endeavors !

G.Rajaganesan, Director - Technical
VATIO Energy India Pvt Ltd.



05th August 2021

Date

Executive Summary

PV Market: Global

- Photovoltaics is a fast-growing market: The Compound Annual Growth Rate (CAGR) of cumulative

PV installations including off-grid was 34% between year 2010 to 2020.

- In year 2020 producers from Asia count for 95% of total c-Si PV module production. China (mainland) holds the lead with a share of 67%. Europe contributed with a share of 3%; USA/LAN with 2%.
- Wafer size increased enabling larger PV module size allowing a power range from +600 W per

module.

- In 2020, Europe's contribution to the total cumulative PV installations amounted to 22% (compared to 24% in 2019). In contrast, installations in China accounted for 33% (same value as the year before).
- Si-wafer based PV technology accounted for about 95% of the total production in 2020. The share of mono-crystalline technology is now about 84% (compared to 66% in 2019) of total c-Si production.
- Market shifts from subsidy driven to competitive pricing model (Power Purchase Agreements

PPA).

Executive Summary

Solar Cell / Module Efficiencies

- The record lab cell efficiency is 26.7% for mono-crystalline and 24.4% for multi-crystalline silicon wafer-based technology. The highest lab efficiency in thin film technology is 23.4% for CIGS and 21.0% for CdTe solar cells. Record lab cell efficiency for Perovskite is 25.5%.

- In the last 10 years, the efficiency of average commercial wafer-based silicon modules increased from

about 1 % to 20%. At the same time, CdTe module efficiency increased from 9% to 19%.

- In the laboratory, best performing modules are based on mono-crystalline silicon with 24.4% efficiency. Record efficiencies demonstrate the potential for further efficiency increases at the production level.
- In the laboratory, high concentration multi-junction solar cells achieve an efficiency of up to 47.1% today. With concentrator technology, module efficiencies of up to 38.9% have been reached.

Executive Summary

Energy Payback Time

- Material usage for silicon cells has been reduced significantly during the last 16 years from around 16 g/Wp to about 3 g/Wp due to increased efficiencies, thinner wafers and diamond wire sawing as well as larger ingots.
- The Energy Payback Time of PV systems is dependent on the geographical location: PV systems in Northern Europe need around 1.2 years to balance the input energy, while PV systems in the South equal their energy input after 1 year and less, depending on the technology installed and the grid efficiency.
- A PV system located in Sicily with wafer-based Silicon modules has an Energy Payback Time of around one year. Assuming 20 years lifespan, this kind of system can produce twenty times the energy needed to produce it.

Executive Summary

Inverters

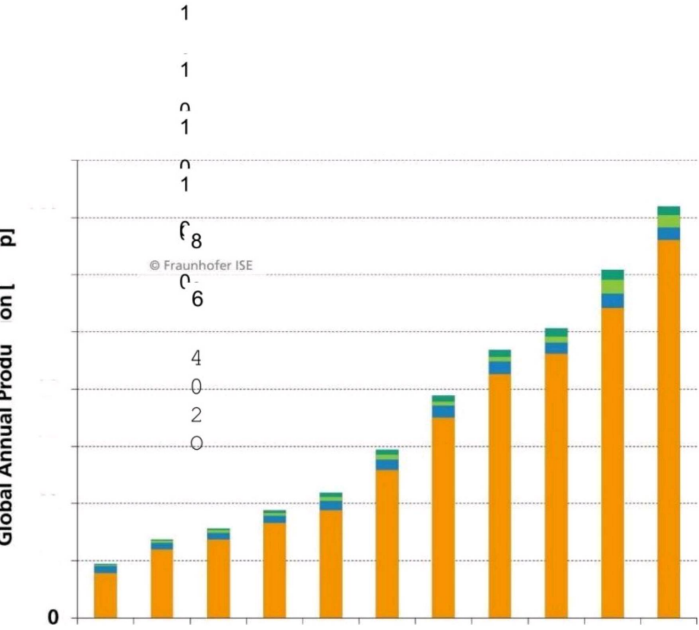
- Inverter efficiency for state-of-the art brand products is 98% and higher.
- The market share of string inverters is estimated to be 64%. These inverters are mostly used in residential, small and medium commercial applications in PV systems up to 150 kWp. The market share of central inverters, with applications mostly in large commercial and utility-scale systems, is about 34%.
A small proportion of the market (about 1%) belongs to micro-inverters (used on the module level). The market share for DC / DC converters, also called "power optimizers", is estimated to be 5% of the total inverter market.
- Trends: Digitalisation, Repowering, new features for grid stabilization and optimization of self-consumption; storage; utilization of innovative semiconductors (SiC or GaN) which allow very high efficiencies and compact designs; 1500 V maximum DC string voltage.

Executive Summary

Price Development

- In Germany prices for a typical 10 to 100 kWp PV rooftop-system were around 14,000 €/kWp in 1990. At the end of 2020, such systems cost only 7.4% of the price in 1990. This is a net-price regression of about 92% over a period of 30 years.
- The Experience Curve – also called Learning Curve - shows that in the last 40 years the module price decreased by 26% with each doubling of the cumulated module production. Cost reduction results from economies of scale and technological improvements.

PV Module Production by Region
Global Annual Production



Asia

2010 2011 2012 2013 2014 2015 2016 2017
2018 2019 2020 Year

Data: IHS Markit 2021. Graph: PPE Projects GmbH 2021

13

About 82% of the global PV module production was from Asia in year 2010. It increased to about 92% of total global production in year 2020. The annual production has increased by a factor of 7 in this decade.

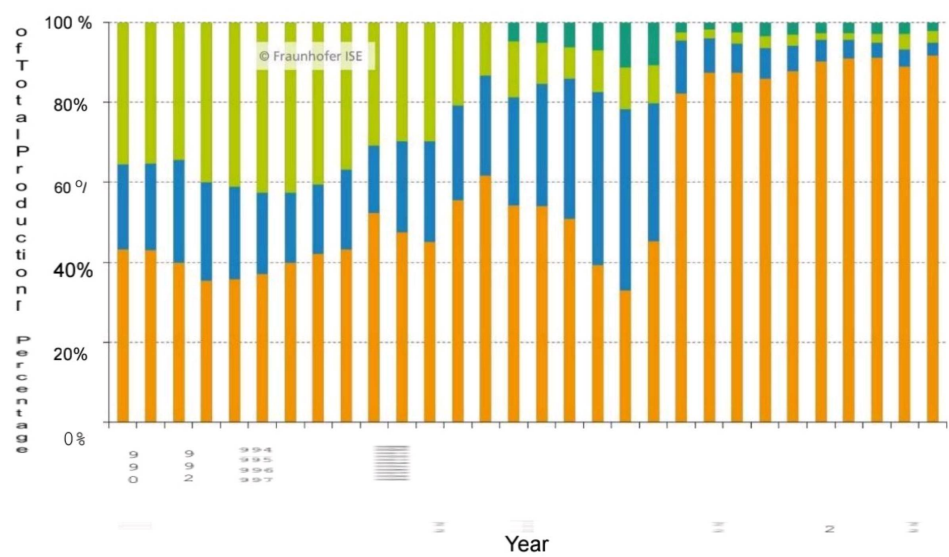
sd Fraunhofer

ISE

Ma 1. PV rket

- region
- technology

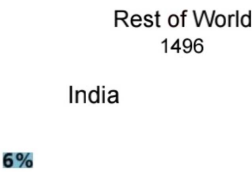
PV Module Production by Region 1990-2020 Percentage of Total MWp Produced



Data: Up to 2004 Strategies Unlimited; 2005 to 2009 Navigant Consulting; since 2010: IHS Markit. Graph: PS E Projects GmbH 2021

Global Cumulative PV Installation by Region

Status 2020

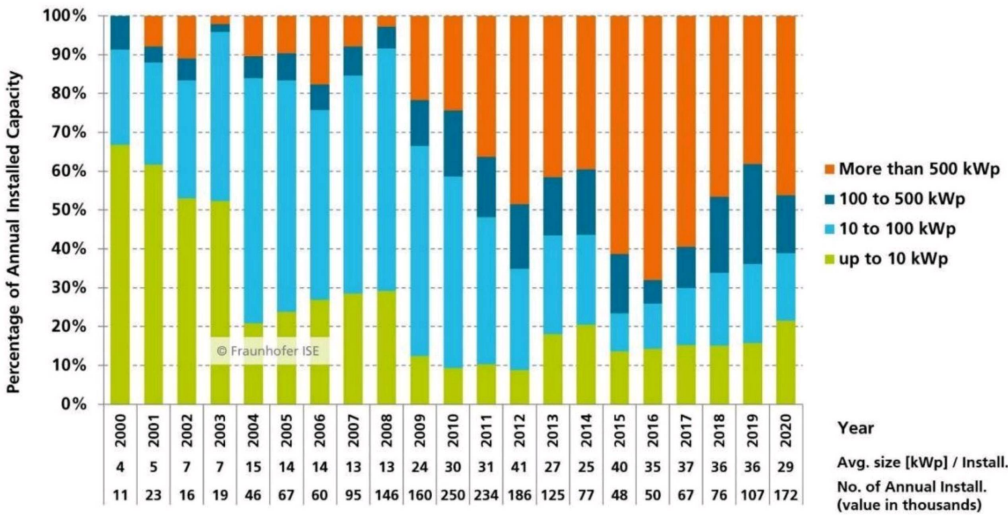


The total cumulative installations amounted to 708 GWp at the end of year 2020.

All percentages are related to global installed PV capacity, including off-grid systems.

Data: IRENA 2021. Graph: PSE Projects GmbH 2021

Number of PV Systems Annually Installed in Germany Percentage of Annual Capacity by System Size

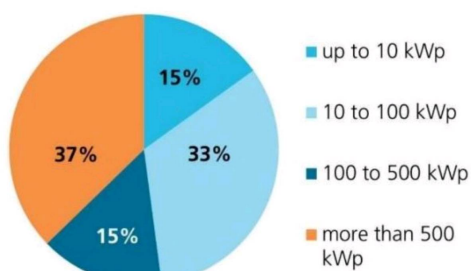


According to BNA at end of year 2020 in Germany a total cumulated PV capacity of 54 GW was installed.

Data: up to 2008: extrapolation from utilities data; since 2009: Bundesnetzagentur (BNA); The compilation is done by filtering initial PV-System operation date. Graph: PSE Projects GmbH 2021

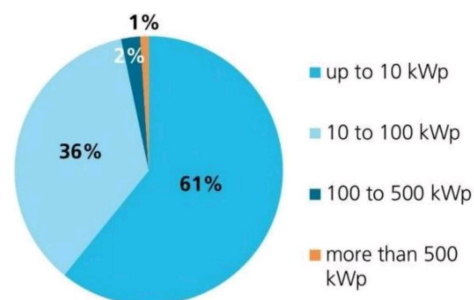
Share of Capacity and Number of PV-Systems Installed Percentage of Cumulative Installations in Germany

Share of PV-Systems in Germany
by cumulative capacity (2020)



© Fraunhofer ISE

Share of PV-Systems in Germany
by cumulative numbers (2020)

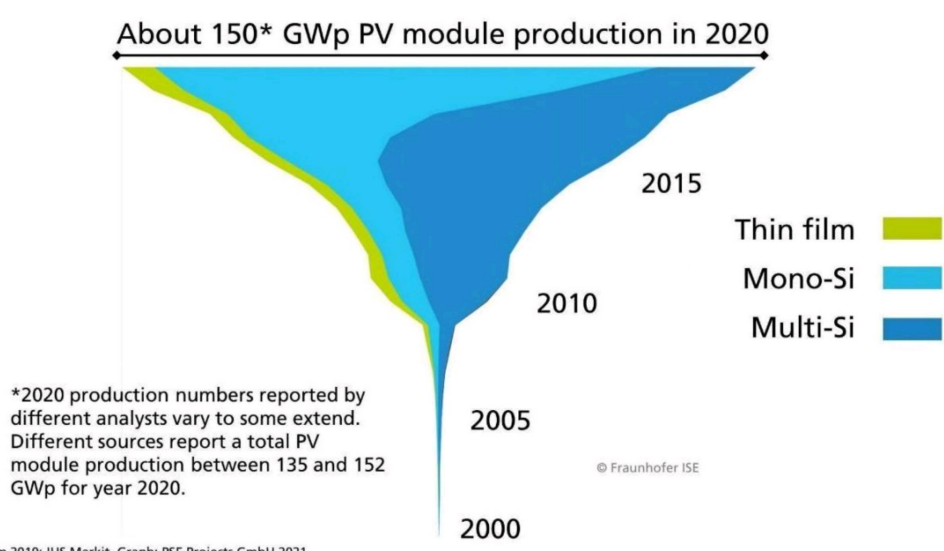


© Fraunhofer ISE

While the larger PV-systems account for about a third of the total installed capacity, the number of large-scale systems with more than 500 kWp is only about 1% of the total installed systems.

Data: Bundesnetzagentur 2021. Graph: PSE Projects GmbH 2021

Annual PV Production by Technology Worldwide (in GWp)

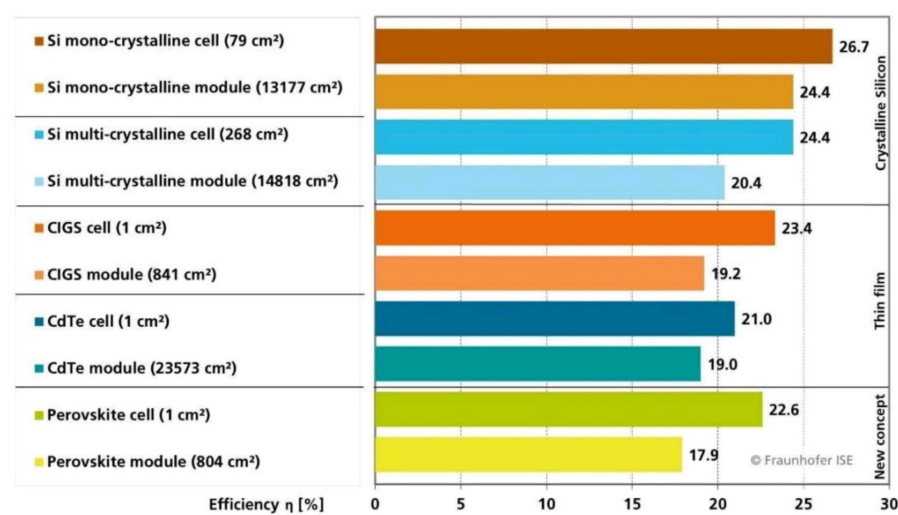


Data: from 2000 to 2009: Navigant; from 2010: IHS Markit. Graph: PSE Projects GmbH 2021

2. Solar Cells / Modules / System Efficiency

- Development in the Laboratories
- Development in the PV Industry
- Performance Ratio (PR)

Efficiency Comparison of Technologies: Best Lab Cells vs. Best Lab Modules

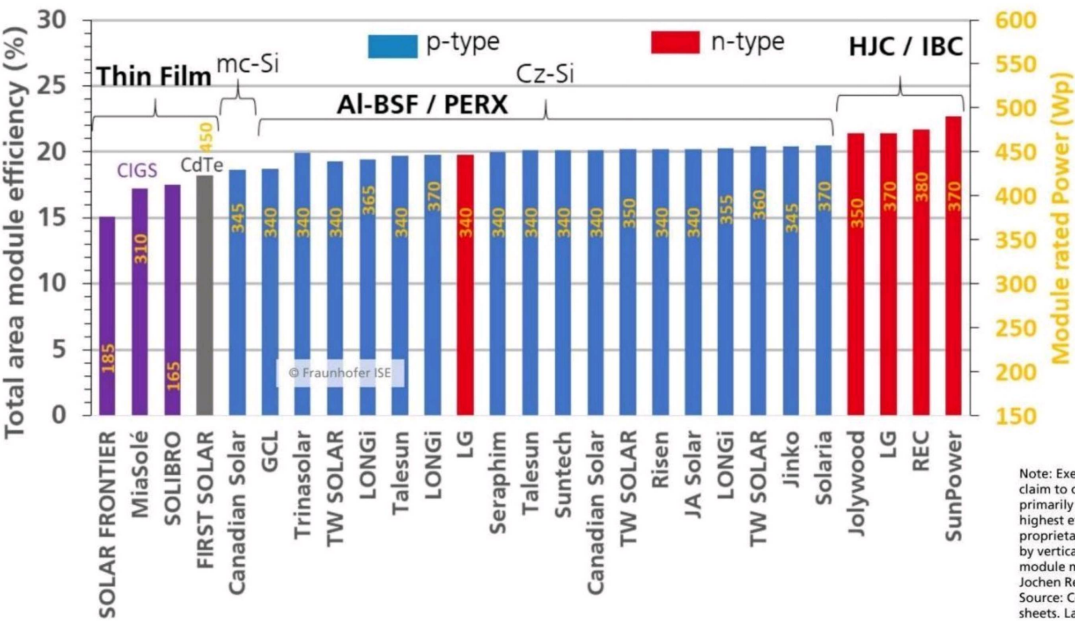


Note: In mass production Cell-to-Module ratio (CTM) improved in past years by reducing losses and using possible gains when integrating solar cells in modules. Fraunhofer ISE provides SmartCalc.CTM software suite for the precise CTM power loss analysis. It considers geometrical losses, optical losses & gains as well as electrical losses.

www.cell-to-module.com

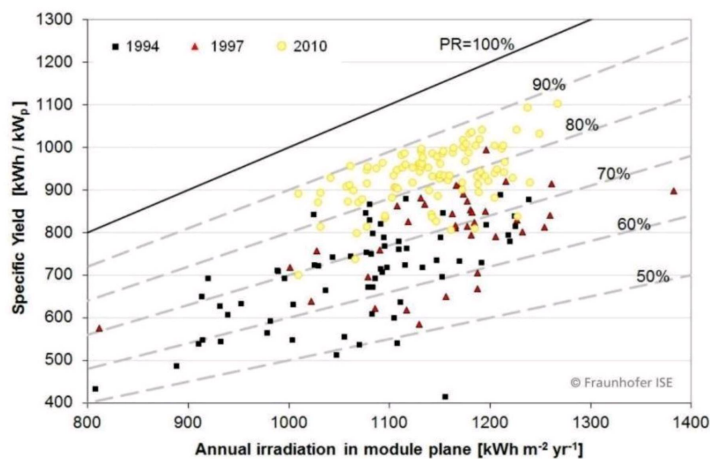
Data: Green et al.: Solar Cell Efficiency Tables (Version 58), Progress in PV: Research and Applications 2020. Graph: PSE Projects GmbH 2021

Current Efficiencies and Power of Selected Commercial PV Modules Sorted by Bulk Material, Cell Concept and Efficiency



Note: Exemplary overview without claim to completeness; Selection is primarily based on modules with highest efficiency of their class and proprietary cell concepts produced by vertically integrated PV cell and module manufacturers; Graph: Jochen Rentsch, Fraunhofer ISE. Source: Company product data sheets. Last update: Nov. 2019.

Performance Ratio Development for PV Systems Germany



In the 1990's

- Typical PR ~70 %
- Widely ranging PR values

Today

- Typical PR ~83 %
- Less variance in PR as compared to 1990's

Source: Fraunhofer ISE "1000 Dächer Jahresbericht" 1994 and 1997; 2011 system evaluation, CPIA 2021

3. Energy Return of Invest (EROI) & Energy Payback Time (EPBT)

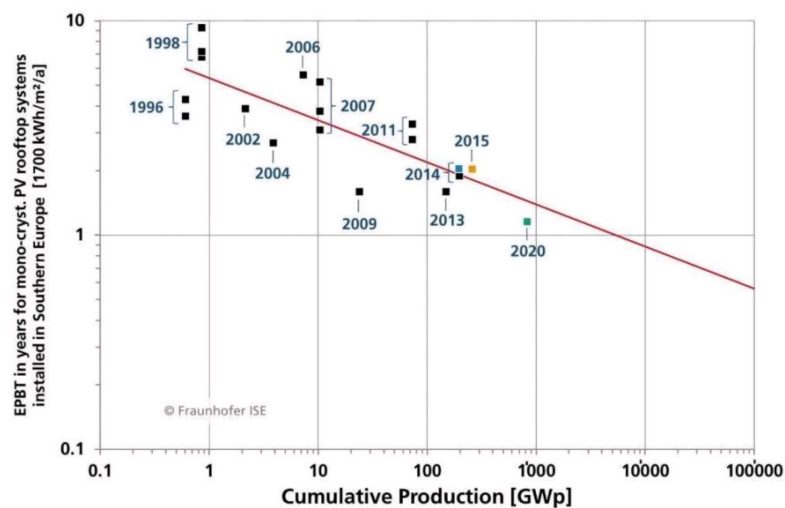
- Silicon usage, wafer thickness and kerf loss for c-Si
- EPBT: Development and comparison

Historic Trend in Energy Payback Time

Harmonized Study data for mono-crystalline Silicon Rooftop PV-Systems

Learning Rate:
Each time the cumulative production doubled, the EPBT went down by 12.8 % for the last 24 years.

Harmonization methodology	
based on Koppelaar (2016) harmonized results and harmonization parameters	
1) Performance Ratio	
based on average annual PV yield during lifetime	
PV system lifetime	25
Degradation	0.70%
PR (initial)	80%
PR (incl. average degradation during lifetime)	73.6%
2) Grid efficiency	
for converting PV yield in primary energy equivalents	
grid efficiency	35%
EPBT of Leccisi (2016), Louwen (2014) and Friedrich (2020) were harmonized with	
1) PR (incl. average degradation) and 2) grid efficiency to results of Koppelaar (2016)*	



Data: Lorenz Friedrich, Fraunhofer ISE. Graph: PSE 2021

* Koppelaar (2016) - Solar-PV energy payback and net energy: Meta-assessment of study quality, reproducibility, and results harmonization, Renewable and Sustainable Energy Reviews
Leccisi et al. (2016) - The Energy and Environmental Performance of Ground-Mounted Photovoltaic Systems—A Timely Update, Energies
Louwen et al. (2014) - Life-cycle greenhouse gas emissions and energy payback time of current and prospective silicon heterojunction solar cell designs, Progress in Photovoltaics
Friedrich et al. (2020) - Global Warming Potential and Energy Payback Time Analysis of Photovoltaic Electricity by Passivated Emitter and Rear Cell (PERC) Solar Modules, submitted JPV

Comparison of EPBT China



efficiency: The better the countries with upstream production is located (better the energy mix to generate electricity, less losses in the transmission network). At downward, we can adhere PV is

EPBT = Energy Pay Back Time in years: Calculated for
PV-system with

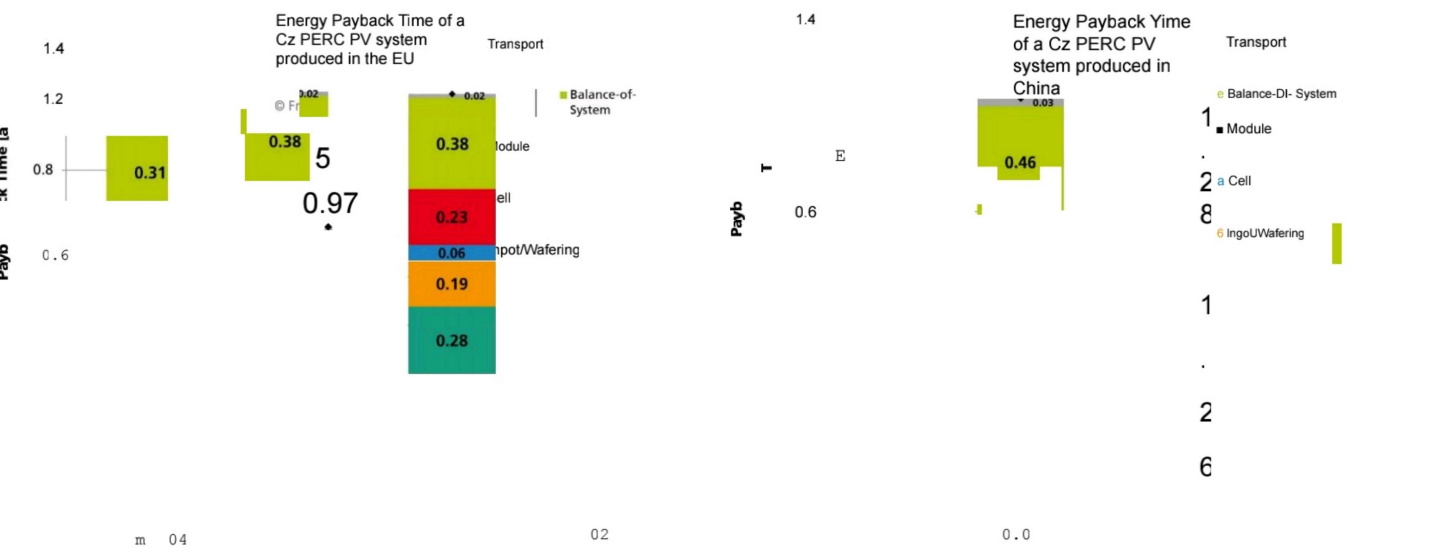
ins a ed) a for grid efficiency
reduces the EPBT.

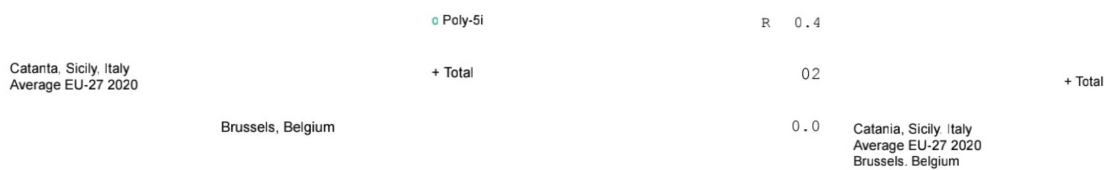
Data: Lorenz Friedrich, Fraunhofer ISE. Graph: PSE 2020

Cz PERC 60 cells modules with 19.9 % efficiency
produced in China



Energy Pay-Back Time of Silicon PV Rooftop Systems — Comparison of EPBT China / EU, local Irradiation and Grid Efficiency





EPBT for PV systems produced in Europe is shorter than for those produced in China because of better grid efficiency in Europe.

Data: Lorenz Friedrich, Fraunhofer ISE. Design: PSE 2020

4. Inverters

- Inverter/Converter Market



Market 2020

Inverter / Converter	Power	Efficiency	Market Share (Estimated)*	Remarks
String Inverters	up to 150 kWp	up to 98%	• 3 17 €-cents Np	
	64.4% Central Inverters		• Easy to replace	
	More than 80 kWp	up to 98.5%	• - 4 €-cents App	
	33.7%		• High reliability	
			• Often sold only together with service contract	
Micro-Inverters				90%-97%
Module Power				



ISE

1.4%

- - 25 G-cents /Wp
- Ease-of-replacement concerns

DC/DC
Converters
(Power
Optimizer)

Module Power up to
99.5% Range

5.1 %

- - 8 €-cents /Wp
- Ease-of-replacement concerns
- Output
DC with
optimized
current

n
t

› Still a DC AC inverter is needed

Data: IHS Mark it 2021. Remarks: Fraunhofer ISE 2020. Design: PSE 2021

*Total Market Share related to shipment in MWac is greater than 100%*A because DC/DC converters are required to be paired with string inverters

5. Price Development

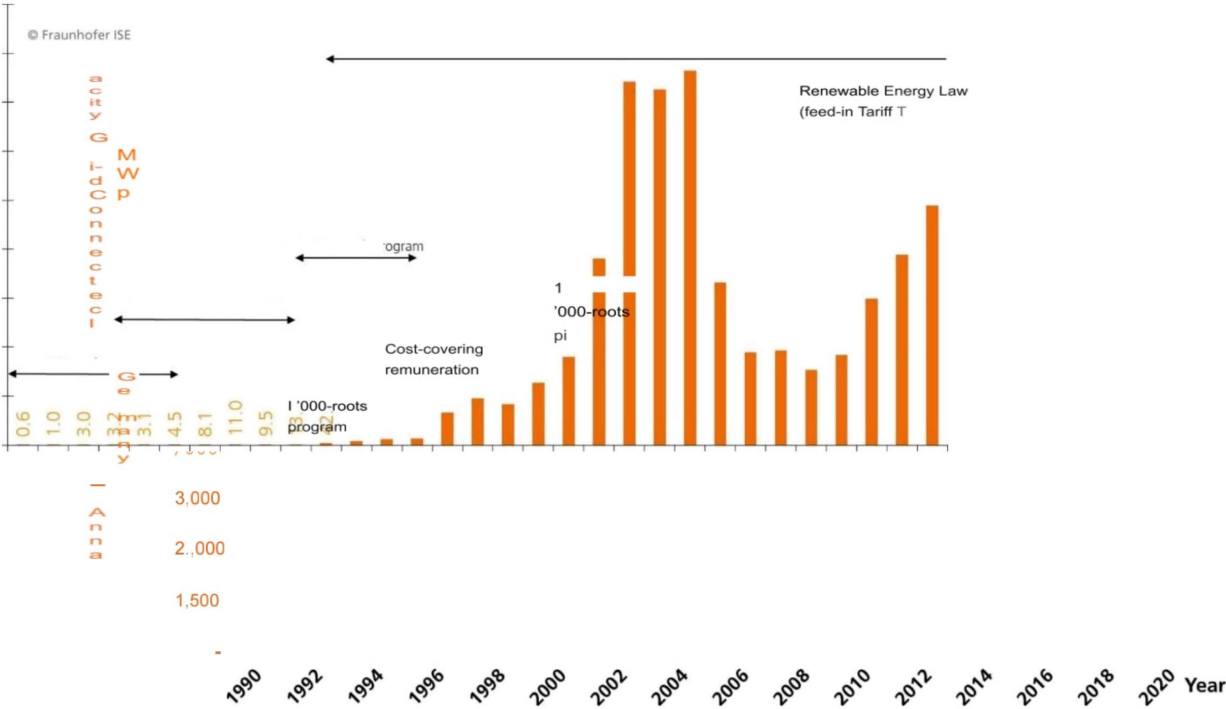
- Electricity costs
- Market incentives in Germany
- Costs for PV systems
- Price Learning Curve



Sun

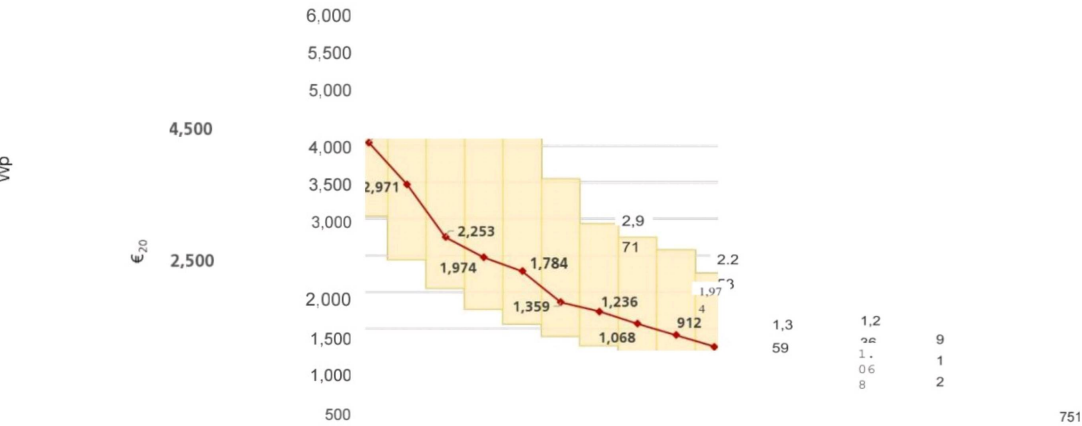
Market Development

bsidy Schemes in Germany



Data: BNA, Graph: PSE 2021

Global Weighted Average Total Installed Costs For Large PV Systems
(with 5th percentile and 95th percentile)



Total installed cost for large PV systems decreased by about 16% on year-to-year basis in the last decade. The 5th percentile is a value

associated with the location within the data where 5% of data is below that

value. In year 2019 the 5th percentile was 539 GkWh. The 95th

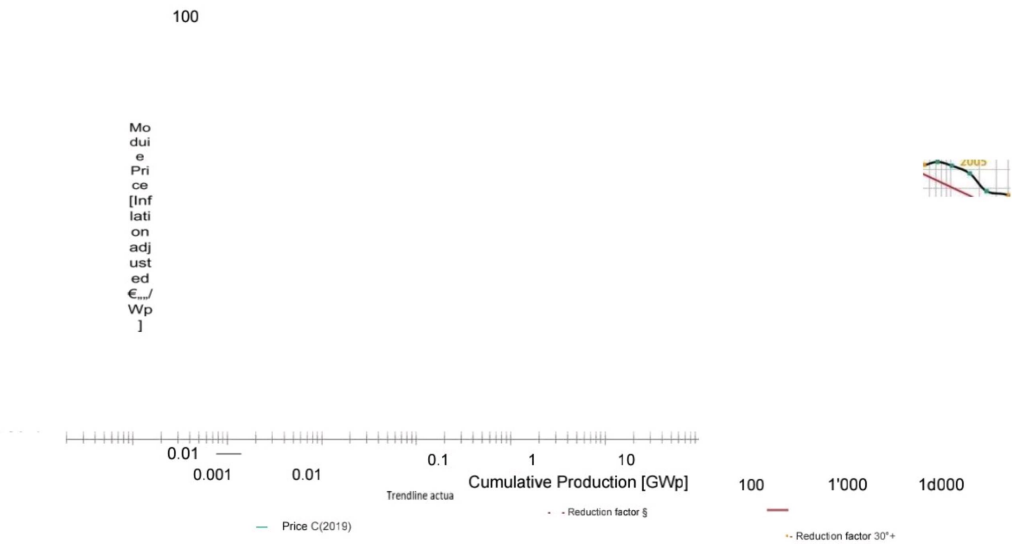
percentile is the value where 5% of the data has is a larger value. In

year 2019 the 95th percentile was 1751 €/kWh.

2019 2018 2017 2016 2015 2014 2013 2012 2011 2010 2009 2008 2007 2006 2005 2004 2003 2002 2001 2000 1999 1998 1997 1996 1995 1994 1993 1992 1991 1990 1989 1988 1987 1986 1985 1984 1983 1982 1981 1980 1979 1978 1977 1976 1975 1974 1973 1972 1971 1970 1969 1968 1967 1966 1965 1964 1963 1962 1961 1960 1959 1958 1957 1956 1955 1954 1953 1952 1951 1950 1949 1948 1947 1946 1945 1944 1943 1942 1941 1940 1939 1938 1937 1936 1935 1934 1933 1932 1931 1930 1929 1928 1927 1926 1925 1924 1923 1922 1921 1920 1919 1918 1917 1916 1915 1914 1913 1912 1911 1910 1909 1908 1907 1906 1905 1904 1903 1902 1901 1900 1899 1898 1897 1896 1895 1894 1893 1892 1891 1890 1889 1888 1887 1886 1885 1884 1883 1882 1881 1880 1879 1878 1877 1876 1875 1874 1873 1872 1871 1870 1869 1868 1867 1866 1865 1864 1863 1862 1861 1860 1859 1858 1857 1856 1855 1854 1853 1852 1851 1850 1849 1848 1847 1846 1845 1844 1843 1842 1841 1840 1839 1838 1837 1836 1835 1834 1833 1832 1831 1830 1829 1828 1827 1826 1825 1824 1823 1822 1821 1820 1819 1818 1817 1816 1815 1814 1813 1812 1811 1810 1809 1808 1807 1806 1805 1804 1803 1802 1801 1800 1799 1798 1797 1796 1795 1794 1793 1792 1791 1790 1789 1788 1787 1786 1785 1784 1783 1782 1781 1780 1779 1778 1777 1776 1775 1774 1773 1772 1771 1770 1769 1768 1767 1766 1765 1764 1763 1762 1761 1760 1759 1758 1757 1756 1755 1754 1753 1752 1751 1750 1749 1748 1747 1746 1745 1744 1743 1742 1741 1740 1739 1738 1737 1736 1735 1734 1733 1732 1731 1730 1729 1728 1727 1726 1725 1724 1723 1722 1721 1720 1719 1718 1717 1716 1715 1714 1713 1712 1711 1710 1709 1708 1707 1706 1705 1704 1703 1702 1701 1700 1699 1698 1697 1696 1695 1694 1693 1692 1691 1690 1689 1688 1687 1686 1685 1684 1683 1682 1681 1680 1679 1678 1677 1676 1675 1674 1673 1672 1671 1670 1669 1668 1667 1666 1665 1664 1663 1662 1661 1660 1659 1658 1657 1656 1655 1654 1653 1652 1651 1650 1649 1648 1647 1646 1645 1644 1643 1642 1641 1640 1639 1638 1637 1636 1635 1634 1633 1632 1631 1630 1629 1628 1627 1626 1625 1624 1623 1622 1621 1620 1619 1618 1617 1616 1615 1614 1613 1612 1611 1610 1609 1608 1607 1606 1605 1604 1603 1602 1601 1600 1599 1598 1597 1596 1595 1594 1593 1592 1591 1590 1589 1588 1587 1586 1585 1584 1583 1582 1581 1580 1579 1578 1577 1576 1575 1574 1573 1572 1571 1570 1569 1568 1567 1566 1565 1564 1563 1562 1561 1560 1559 1558 1557 1556 1555 1554 1553 1552 1551 1550 1549 1548 1547 1546 1545 1544 1543 1542 1541 1540 1539 1538 1537 1536 1535 1534 1533 1532 1531 1530 1529 1528 1527 1526 1525 1524 1523 1522 1521 1520 1519 1518 1517 1516 1515 1514 1513 1512 1511 1510 1509 1508 1507 1506 1505 1504 1503 1502 1501 1500 1499 1498 1497 1496 1495 1494 1493 1492 1491 1490 1489 1488 1487 1486 1485 1484 1483 1482 1481 1480 1479 1478 1477 1476 1475 1474 1473 1472 1471 1470 1469 1468 1467 1466 1465 1464 1463 1462 1461 1460 1459 1458 1457 1456 1455 1454 1453 1452 1451 1450 1449 1448 1447 1446 1445 1444 1443 1442 1441 1440 1439 1438 1437 1436 1435 1434 1433 1432 1431 1430 1429 1428 1427 1426 1425 1424 1423 1422 1421 1420 1419 1418 1417 1416 1415 1414 1413 1412 1411 1410 1409 1408 1407 1406 1405 1404 1403 1402 1401 1400 1399 1398 1397 1396 1395 1394 1393 1392 1391 1390 1389 1388 1387 1386 1385 1384 1383 1382 1381 1380 1379 1378 1377 1376 1375 1374 1373 1372 1371 1370 1369 1368 1367 1366 1365 1364 1363 1362 1361 1360 1359 1358 1357 1356 1355 1354 1353 1352 1351 1350 1349 1348 1347 1346 1345 1344 1343 1342 1341 1340 1339 1338 1337 1336 1335 1334 1333 1332 1331 1330 1329 1328 1327 1326 1325 1324 1323 1322 1321 1320 1319 1318 1317 1316 1315 1314 1313 1312 1311 1310 1309 1308 1307 1306 1305 1304 1303 1302 1301 1300 1299 1298 1297 1296 1295 1294 1293 1292 1291 1290 1289 1288 1287 1286 1285 1284 1283 1282 1281 1280 1279 1278 1277 1276 1275 1274 1273 1272 1271 1270 1269 1268 1267 1266 1265 1264 1263 1262 1261 1260 1259 1258 1257 1256 1255 1254 1253 1252 1251 1250 1249 1248 1247 1246 1245 1244 1243 1242 1241 1240 1239 1238 1237 1236 1235 1234 1233 1232 1231 1230 1229 1228 1227 1226 1225 1224 1223 1222 1221 1220 1219 1218 1217 1216 1215 1214 1213 1212 1211 1210 1209 1208 1207 1206 1205 1204 1203 1202 1201 1200 1199 1198 1197 1196 1195 1194 1193 1192 1191 1190 1189 1188 1187 1186 1185 1184 1183 1182 1181 1180 1179 1178 1177 1176 1175 1174 1173 1172 1171 1170 1169 1168 1167 1166 1165 1164 1163 1162 1161 1160 1159 1158 1157 1156 1155 1154 1153 1152 1151 1150 1149 1148 1147 1146 1145 1144 1143 1142 1141 1140 1139 1138 1137 1136 1135 1134 1133 1132 1131 1130 1129 1128 1127 1126 1125 1124 1123 1122 1121 1120 1119 1118 1117 1116 1115 1114 1113 1112 1111 1110 1109 1108 1107 1106 1105 1104 1103 1102 1101 1100 1099 1098 1097 1096 1095 1094 1093 1092 1091 1090 1089 1088 1087 1086 1085 1084 1083 1082 1081 1080 1079 1078 1077 1076 1075 1074 1073 1072 1071 1070 1069 1068 1067 1066 1065 1064 1063 1062 1061 1060 1059 1058 1057 1056 1055 1054 1053 1052 1051 1050 1049 1048 1047 1046 1045 1044 1043 1042 1041 1040 1039 1038 1037 1036 1035 1034 1033 1032 1031 1030 1029 1028 1027 1026 1025 1024 1023 1022 1021 1020 1019 1018 1017 1016 1015 1014 1013 1012 1011 1010 1009 1008 1007 1006 1005 1004 1003 1002 1001 1000 999 998 997 996 995 994 993 992 991 990 989 988 987 986 985 984 983 982 981 980 979 978 977 976 975 974 973 972 971 970 969 968 967 966 965 964 963 962 961 960 959 958 957 956 955 954 953 952 951 950 949 948 947 946 945 944 943 942 941 940 939 938 937 936 935 934 933 932 931 930 929 928 927 926 925 924 923 922 921 920 919 918 917 916 915 914 913 912 911 910 909 908 907 906 905 904 903 902 901 900 899 898 897 896 895 894 893 892 891 890 889 888 887 886 885 884 883 882 881 880 879 878 877 876 875 874 873 872 871 870 869 868 867 866 865 864 863 862 861 860 859 858 857 856 855 854 853 852 851 850 849 848 847 846 845 844 843 842 841 840 839 838 837 836 835 834 833 832 831 830 829 828 827 826 825 824 823 822 821 820 819 818 817 816 815 814 813 812 811 810 809 808 807 806 805 804 803 802 801 800 799 798 797 796 795 794 793 792 791 790 789 788 787 786 785 784 783 782 781 780 779 778 777 776 775 774 773 772 771 770 769 768 767 766 765 764 763 762 761 760 759 758 757 756 755 754 753 752 751 750 749 748 747 746 745 744 743 742 741 740 739 738 737 736 735 734 733 732 731 730 729 728 727 726 725 724 723 722 721 720 719 718 717 716 715 714 713 712 711 710 709 708 707 706 705 704 703 702 701 700 699 698 697 696 695 694 693 692 691 690 689 688 687 686 685 684 683 682 681 680 679 678 677 676 675 674 673 672 671 670 669 668 667 666 665 664 663 662 661 660 659 658 657 656 655 654 653 652 651 650 649 648 647 646 645 644 643 642 641 640 639 638 637 636 635 634 633 632 631 630 629 628 627 626 625 624 623 622 621 620 619 618 617 616 615 614 613 612 611 610 609 608 607 606 605 604 603 602 601 600 599 598 597 596 595 594 593 592 591 590 589 588 587 586 585 584 583 582 581 580 579 578 577 576 575 574 573 572 571 570 569 568 567 566 565 564 563 562 561 560 559 558 557 556 555 554 553 552 551 550 549 548 547 546 545 544 543 542 541 540 539 538 537 536 535 534 533 532 531 530 529 528 527 526 525 524 523 522 521 520 519 518 517 516 515 514 513 512 511 510 509 508 507 506 505 504 503 502 501 500 499 498 497 496 495 494 493 492 491 490 489 488 487 486 485 484 483 482 481 480 479 478 477 476 475 474 473 472 471 470 469 468 467 466 465 464 463 462 461 460 459 458 457 456 455 454 453 452 451 450 449 448 447 446 445 444 443 442 441 440 439 438 437 436 435 434 433 432 431 430 429 428 427 426 425 424 423 422 421 420 419 418 417 416 415 414 413 412 411 410 409 408 407 406 405 404 403 402 401 400 399 398 397 396 395 394 393 392 391 390 389 388 387 386 385 384 383 382 381 380 379 378 377 376 375 374 373 372 371 370 369 368 367 366 365 364 363 362 361 360 359 358 357 356 355 354 353 352 351 350 349 348 347 346 345 344 343 342 341 340 339 338 337 336 335 334 333 332 331 330 329 328 327 326 325 324 323 322 321 320 319 318 317 316 315 314 313 312 311 310 309 308 307 306 305 304 303 302 301 300 299 298 297 296 295 294 293 292 291 290 289 288 287 286 285 284 283 282 281 280 279 278 277 276 275 274 273 272 271 270 269 268 267 266 265 264 263 262 261 260 259 258 257 256 255 254 253 252 251 250 249 248 247 246 245 244 243 242 241 240 239 238 237 236 235 234 233 232 231 230 229 228 227 226 225 224 223 222 221 220 219 218 217 216 215 214 213 212 211 210 209 208 207 206 205 204 203 202 201 200 199 198 197 196 195 194 193 192 191 190 189 188 187 186 185 184 183 182 181 180 179 178 177 176 175 174 173 172 171 170 169 168 167 166 165 164 163 162 161 160 159 158 157 156 155 154 153 152 151 150 149 148 147 146 145 144 143 142 141 140 139 138 137 136 135 134 133 132 131 130 129 128 127 126 125 124 123 122 121 120 119 118 117 116 115 114 113 112 111 110 109 108 107 106 105 104 103 102 101 100 99 98 97 96 95 94 93 92 91 90 89 88 87 86 85 84 83 82 81 80 79 78 77 76 75 74 73 72 71 70 69 68 67 66 65 64 63 62 61 60 59 58 57 56 55 54 53 52 51 50 49 48 47 46 45 44 43 42 41 40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

Data: IRENA (2020), Renewable Power Generation Costs in 2019, International Renewable Energy Agency, Abu Dhabi. Currency converted from USD to EUR.

Price Learning Curve
Includes all Commercially Available PV Technologies



Learning Rate:

Each
time

the
cumula
tive PV
modul
e
produc

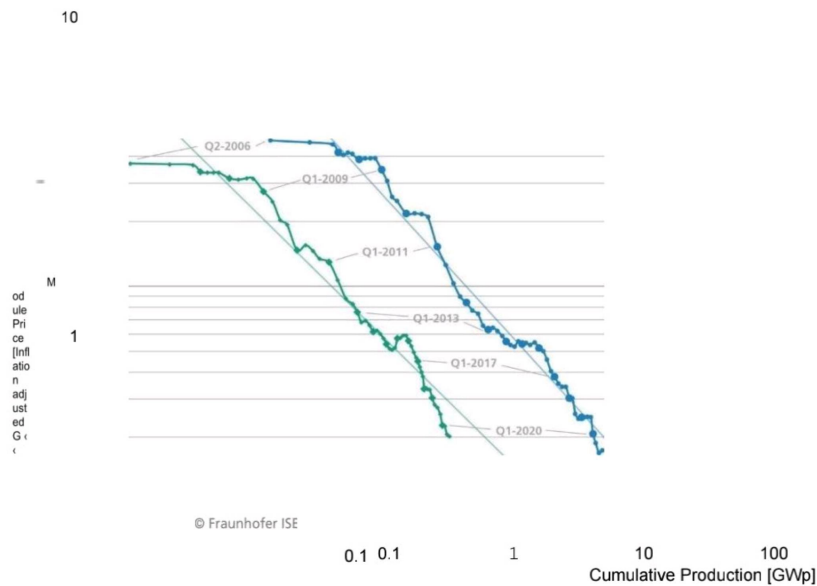
tion
double
d, the
price
went

down
by
25%
for the
last 40
years.

Data: from 1980 to 2010 estimation from different sources: Strategies Unlimited, Navigant Consulting, EUPD, pvXchange; from 2011: IHS Markit; Graph: PSE 2021

Price Learning Curve by Technology

Cumulative Production up to Q4-2020



Estimated cumulative PV module

production up to Q4-2020:

e c-Si 773 GWp
+ Thin Film 52 GWp

Crystalline Technology
(from Q2-2006 to Q4-2020) LR 32
Thin Film Technology
(from Q2-2006 to Q4-2020) LR 30

Data: from 2006 to 2010 estimation from different sources : Navigant Consulting, EUPD, pvXchange; from 2011: IHS Markit. Graph: PSE 2021

Abbreviations

Abbr.	Explanation	Abbr.	Explanation
AC	Alternating Current	HCPV	High Concentrator Photovoltaic
Al-BS	Aluminum Back Surface	HJT (also	
F	Field Building Integrated PV	HIT) IBC	Heterojunction with Intrinsic Thin-Layer
BIPV	Balance of System	LCPV	Interdigitated Back Contact (solar cells)
BOS			Low Concentrator Photovoltaic
CdTe	Cadmium-Telluride	MJ	Multi Junction
CI(G)S	Copper Indium (Gallium)Diselenide	MPP	Maximum Power Point
CPV	Concentrating Photovoltaic	n-type	Negatively doped wafer (with phosphorous)
c-Si	Crystalline Silicon	PERC	Passivated emitter and rear cell
Cz	Czochralski Method	PR	Performance Ratio
DC	Direct current	p-type	Positively doped wafer (with boron)
EEG		Renewable Energy	GalTium
EPBT	EROI	Law (Erneuerbare	Arsenide
FZ		Energie Gesetz)	Gallium
GaAs		Energy PayBack Time	nitride
GaN		Energy Return of	
		Invest	
		Floating	
		Zone	
			PV
			RE ROI SI
			SIc
			VAT

Photovoltaic

Renewable Energies

Return on Investment

Silicon

Silicon carbide

Value Added Tax

_Fraunhofer

ISE

Acknowledgements

This work has been carried out with contributions from:

Name	Institution
Bruno Burger	ISE
Lorenz Friedrich	ISE
Christoph Kost	ISE
Sebastian Nold	ISE
Simon Philipps	ISE
Ralf Preu	ISE
Jochen Rentsch	ISE
Thomas Schlegl	ISE
Gerhard Stryi-Hipp	ISE
Harry Wirth	ISE
Werner Warmuth	PSE

The information provided in this 'Photovoltaics Report' is very concise by its nature and the purpose is to provide a rough overview about the Solar PV market, the technology and environmental impact.

There are many more aspects and further details can be provided by Fraunhofer ISE. Upon request, you are welcome to receive a tailor-made offer.

Please contact us if you are interested in ordering this service.

simon.philipps@ise.fraunhofer.de
warmuth@pse-projects.de

THANK
YOU!
