Data in brief

Data Article

Dataset on the global patent networks within and between vehicle powertrain technologies — Cases of ICEV, HEV, and BEV

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Abstract

The emergence of networks is a crucial channel for automotive organisations to build and diffuse the required environmental innovations in the transportation sector and accelerate the transition to the green mobility economy. This article contains the dataset regarding the global patents networks shaped both within and between the three vehicle powertrains of internal combustion engine vehicle (ICEV), hybrid electric vehicle (HEV) and battery electric vehicle (BEV) for the period of 1985–2016. The data was acquired from Thomson Reuters’ Derwent Innovations Index (DII) platform using the elements of ‘patent families’ and ‘priority dates’. We describe the dataset for the three major automotive periods of ‘towards sustainable mobility’ (1985–1996), ‘towards hybridisation’ (1997–2007), and ‘towards mass commercialisation’ (2008–2016). The dataset bears on two levels, individual and mutual, and we used a separate combined search strategy of keywords and IPCs codes (international patent classification) for each level. At individual level, we explored the internal network features of each powertrain individually (i.e. ICEV, HEV, and BEV). Monitoring a total of 78,732 patents in the three individual powertrain networks, we discovered a total of 1856 unique parent organisations connecting vis-à-vis 5849 bilateral relationships and operating around 4450 joint patents. At mutual level, we explored the mutually common network features of the powertrains (i.e. ICEV–HEV, HEV–BEV, and BEV–ICEV). Monitoring a total of 4702

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patents in the three mutual powertrain networks, we discovered a total of 102 unique parent organisations connecting vis-à-vis 384 bilateral relationships and operating around 303 joint patents. These organisations were found specialised around 435 unique subgroup-level IPC codes, of which 134 codes were related to environmentally friendly innovations. The dataset presented in this article is used in [1] and allows researchers not only to map and model the network dynamics and structures within and between the powertrains at global level, but also to analyse and forecast their knowledge flows, technical domains and environmental innovations aspect, using a wide range of models such as social network analysis or regression.

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Specifications Table

| Subject                          | Transportation, Management of Technology and Innovation |
|---------------------------------|--------------------------------------------------------|
| Specific subject area           | Vehicle powertrains, Electric vehicles, Networks, Collaborations, Patent bibliometrics |
| Type of data                    | CSV files, and figures and tables in the article.     |
| How data were acquired          | Data were acquired from Thomson Reuters' Derwent Innovations Index. |
| Data format                     | Raw and processed data.                               |
| Parameters for data collection  | Data collection occurred in November of 2018. We collected data regarding the global patents networks shaped both within and between ICEV, HEV, and BEV for the three periods of 1985–1996, 1997–2007, and 2008–2016. Using separate combined search strategies of keywords and IPCs, the data were extracted and processed based on 'patent families' and 'priority date'. |
| Description of data collection  | Dataset bears on two levels. At individual level (e.g. BEV, or HEV), three individual networks were found with a total of 1856 unique parent organisations connecting vis-à-vis 5849 bilateral relationships while operating around 4450 joint patents. At mutual level (e.g. HEV-BEV), three networks were found with a total of 102 unique parent organisations connecting vis-à-vis 384 bilateral relationships while operating around 303 joint patents. The organisations were found specialised around 435 subgroup-level IPC codes, of which 134 codes were related to environmentally friendly innovations. |
| Data source location            | The University of Newcastle, 409 Hunter Street, Newcastle, NSW, 2300, Australia |
| Data accessibility              | With the article                                      |
| Related research article        | Mirzadeh Phirouzabadi, A., Juniper, J., Savage, D., Blackmore, K., Supportive or inhibitive? —Analysis of dynamic interactions between the interorganisational collaborations of vehicle powertrains, Journal of Cleaner Production, in press, https://doi.org/10.1016/j.jclepro.2019.118790 |

Value of the Data

- A comprehensive database is provided regarding the patents networks that have been shaped both within and between the three powertrains of ICEV, HEV, and BEV at global level for the three major automotive periods of 1985–1996, 1997–2007, and 2008–2016.
- This dataset is valuable for researchers interested not only in mapping and modelling the network dynamics and structures within and between the vehicle powertrains on a global scale, but also in analysing and forecasting the complexity and advancement of their knowledge domains and environmental innovations.
- The dataset can be employed and analysed by a wide range of models such as social network analysis and regression models.
- The dataset can be completed or extended either by collecting collaboration data other than joint patents such as joint ventures and alliances, or by including other powertrain alternatives such as fuel cell vehicles (FCV).
1. Data

This article contains and describes a dataset at global scale regarding the patents networks that have been shaped both within and between the three vehicle powertrains of internal combustion engine vehicle (ICEV), hybrid electric vehicle (HEV) and battery electric vehicle (BEV). While the dataset timeframe is between 1985 and 2016, the data will be described for the three individual periods of 1985–1996, 1997–2007, and 2008–2016.

Our dataset is used in Ref. [1] and bears on two levels, individual and mutual. At individual level, we collected and processed the patent network data within individual powertrain systems. At mutual level, we collected and processed the common patent network data between the powertrain systems. While the tables and figures shown in the following sub-sections outline the various features of our dataset at both individual and mutual levels, the full dataset is attached as Supplementary Appendix.

1.1. Data at individual level

At individual level, we extracted a total of 78,732 patents related to individual powertrain systems (i.e. HEV, BEV, and ICEV) in order to explore their internal network features. We discovered a total of 1856 unique parent organisations connecting vis-à-vis 5849 bilateral relationships and operating around 4450 joint patents.

Table 1 shows the absolute and relative number of joint patents within each powertrain system over the entire period. An Excel file is included in the Supplementary appendix of this article, which contains the absolute and relative number of joint patents at individual level between 1985 and 2016.

| Year | BEV | HEV | ICEV | BEV% | HEV% | ICEV% |
|------|-----|-----|------|------|------|------|
| 1985 | 0   | 0   | 19   | 0.00%| 0.00%| 100.00%|
| 1986 | 0   | 0   | 13   | 0.00%| 0.00%| 100.00%|
| 1987 | 0   | 0   | 19   | 0.00%| 0.00%| 100.00%|
| 1988 | 1   | 0   | 13   | 7.14%| 0.00%| 92.86% |
| 1989 | 1   | 0   | 17   | 5.56%| 0.00%| 94.44% |
| 1990 | 1   | 0   | 18   | 5.26%| 0.00%| 94.74% |
| 1991 | 0   | 0   | 31   | 0.00%| 0.00%| 100.00%|
| 1992 | 3   | 0   | 19   | 13.64%| 0.00%| 86.36% |
| 1993 | 8   | 0   | 28   | 22.22%| 0.00%| 77.78% |
| 1994 | 6   | 0   | 26   | 18.75%| 0.00%| 81.25% |
| 1995 | 4   | 2   | 45   | 7.84%| 3.92%| 88.24% |
| 1996 | 5   | 0   | 36   | 12.20%| 0.00%| 87.80% |
| 1997 | 13  | 4   | 48   | 20.00%| 6.15%| 73.85% |
| 1998 | 12  | 4   | 36   | 23.08%| 7.69%| 69.23% |
| 1999 | 31  | 4   | 47   | 37.80%| 4.88%| 57.32% |
| 2000 | 42  | 13  | 59   | 36.84%| 11.40%| 51.75% |
| 2001 | 25  | 6   | 73   | 24.04%| 5.77%| 70.19% |
| 2002 | 20  | 17  | 90   | 15.75%| 13.39%| 70.87% |
| 2003 | 32  | 30  | 146  | 15.38%| 14.42%| 70.19% |
| 2004 | 37  | 43  | 127  | 17.87%| 20.77%| 61.35% |
| 2005 | 34  | 36  | 142  | 16.04%| 16.98%| 66.98% |
| 2006 | 32  | 39  | 165  | 13.56%| 16.53%| 69.92% |
| 2007 | 54  | 75  | 165  | 18.37%| 25.51%| 56.12% |
| 2008 | 59  | 69  | 135  | 22.43%| 26.24%| 51.33% |
| 2009 | 107 | 41  | 106  | 42.13%| 16.14%| 41.73% |
| 2010 | 166 | 63  | 152  | 43.57%| 16.54%| 39.90% |
| 2011 | 246 | 65  | 125  | 56.42%| 14.91%| 28.67% |
| 2012 | 225 | 57  | 127  | 55.01%| 13.94%| 31.05% |
| 2013 | 154 | 34  | 101  | 53.29%| 11.76%| 34.95% |
| 2014 | 108 | 32  | 70   | 51.43%| 15.24%| 33.33% |
| 2015 | 44  | 30  | 52   | 34.92%| 23.81%| 41.27% |
| 2016 | 27  | 19  | 20   | 40.91%| 28.79%| 30.30% |
| Sum  | 1497| 683 | 2270 | 33.64%| 15.35%| 51.01% |
Table 2 shows the absolute and relative number of the bilateral relationships shaped among the parent organisations of each powertrain system over the entire period. An Excel file is included in the Supplementary appendix of this article, which contains the absolute and relative number of bilateral relationships at individual level between 1985 and 2016.

Fig. 1 displays the most frequent bilateral relationships shaped among the parent organisations of each powertrain system for the period 1985–1996. The related raw data lists all the organisations that were in collaboration in the field of individual powertrain systems for the development of joint patents granted between 1985 and 1996.

Fig. 2 displays the most frequent bilateral relationships shaped among the parent organisations of each powertrain system for the period 1997–2007. The related raw data lists all the collaborating organisations which developed the joint patents granted between 1997 and 2007 in the field of individual powertrain systems.

Fig. 3 displays the most frequent bilateral relationships shaped among the parent organisations of each powertrain system for the period 2008–2016. The related raw data lists all the organisations which collaborated in the field of individual powertrain systems for the development of joint patents granted between 2008 and 2016.

An Excel file is included in the Supplementary appendix of this article, which contains all the raw data related to the collaborating organisations at individual level over 1985–1996, 1997–2007, and 2008–2016 as well as the entire period 1985–2016.

| Year | BEV | HEV | ICEV | BEV% | HEV% | ICEV% |
|------|-----|-----|------|------|------|------|
| 1985 | 0   | 0   | 23   | 0.00%| 0.00%| 100.00%|
| 1986 | 0   | 0   | 17   | 0.00%| 0.00%| 100.00%|
| 1987 | 0   | 0   | 19   | 0.00%| 0.00%| 100.00%|
| 1988 | 1   | 0   | 17   | 5.56%| 0.00%| 94.44% |
| 1989 | 1   | 0   | 21   | 4.55%| 0.00%| 95.45% |
| 1990 | 1   | 0   | 22   | 4.35%| 0.00%| 95.65% |
| 1991 | 0   | 0   | 33   | 0.00%| 0.00%| 100.00%|
| 1992 | 3   | 0   | 19   | 13.64%| 0.00%| 86.36% |
| 1993 | 8   | 0   | 56   | 12.50%| 0.00%| 87.50% |
| 1994 | 4   | 0   | 39   | 9.30%| 0.00%| 90.70% |
| 1995 | 1   | 2   | 93   | 1.04%| 2.08%| 96.88% |
| 1996 | 5   | 0   | 42   | 10.64%| 0.00%| 89.36% |
| 1997 | 13  | 4   | 63   | 16.25%| 5.00%| 78.75% |
| 1998 | 12  | 4   | 84   | 12.00%| 4.00%| 84.00% |
| 1999 | 40  | 4   | 61   | 38.10%| 3.81%| 58.10% |
| 2000 | 50  | 13  | 70   | 37.59%| 9.77%| 52.63% |
| 2001 | 27  | 20  | 331  | 7.14%| 5.29%| 87.57% |
| 2002 | 22  | 17  | 375  | 5.31%| 4.11%| 90.58% |
| 2003 | 34  | 30  | 291  | 9.58%| 8.45%| 81.97% |
| 2004 | 39  | 47  | 187  | 14.29%| 17.22%| 68.50% |
| 2005 | 36  | 40  | 156  | 15.52%| 17.24%| 67.24% |
| 2006 | 36  | 41  | 186  | 13.69%| 15.59%| 70.72% |
| 2007 | 60  | 83  | 194  | 17.80%| 24.63%| 57.57% |
| 2008 | 63  | 94  | 152  | 20.39%| 30.42%| 49.19% |
| 2009 | 112 | 41  | 122  | 40.73%| 14.91%| 44.36% |
| 2010 | 178 | 73  | 185  | 40.83%| 16.74%| 42.43% |
| 2011 | 258 | 67  | 141  | 55.36%| 14.38%| 30.26% |
| 2012 | 267 | 61  | 138  | 57.30%| 13.09%| 29.61% |
| 2013 | 176 | 34  | 115  | 54.15%| 10.46%| 35.38% |
| 2014 | 129 | 32  | 93   | 50.79%| 12.60%| 36.61% |
| 2015 | 52  | 35  | 62   | 34.90%| 23.49%| 41.61% |
| 2016 | 29  | 23  | 20   | 40.28%| 31.94%| 27.78% |
| Sum  | 1657| 765 | 3427 | 28.33%| 13.08%| 58.59% |
Fig. 1. The most frequent bilateral relationships at individual level for the period 1985–1996.

Fig. 2. The most frequent bilateral relationships at individual level for the period 1997–2007.

Fig. 3. The most frequent bilateral relationships at individual level for the period 2008–2016.
1.2. Data at mutual level

At mutual level, we explored the common network features for each pair of the powertrain systems, i.e. ICEV-BEV, HEV-BEV, and ICEV-HEV. After extracting and exploring through a total of 4702 common patents, the three common networks were found with a total of 102 unique parent organisations connecting vis-à-vis 384 bilateral relationships and operating around 303 joint patents.

Table 3 shows the absolute and relative number of the joint patents shared between two powertrain systems over the entire period. An Excel file is included in the Supplementary appendix of this article, which contains the absolute and relative number of joint patents shared at mutual level between 1985 and 2016.

Table 4 shows the absolute and relative number of the bilateral relationships shared between two powertrain systems over the entire period. An Excel file is included in the Supplementary appendix of this article, which contains the absolute and relative number of bilateral relationships shared at mutual level between 1985 and 2016.

Fig. 4 displays the most frequent bilateral relationships shaped among the parent organisations of two powertrain systems for the period 1985–1996. The related raw data lists all the organisations that were in collaboration for the development of joint patents shared between two powertrain systems over 1985–1996.

Fig. 5 displays the most frequent bilateral relationships shaped among the parent organisations of two powertrain systems for the period 1997–2007. The related raw data lists all the collaborating organisations which developed the joint patents shared between two powertrain systems over 1997–2007.

Table 3
The absolute and relative number of shared joint patents at mutual level (1985–2016).

| Year | ICEV-BEV | HEV-BEV | ICEV-HEV | ICEV-BEV% | HEV-BEV% | ICEV-HEV% |
|------|----------|---------|----------|-----------|----------|-----------|
| 1985 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1986 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1987 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1988 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1989 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1990 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1991 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1992 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1993 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1994 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1995 | 1        | 0       | 1        | 50.00%    | 0.00%    | 50.00%    |
| 1996 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1997 | 1        | 1       | 2        | 25.00%    | 25.00%   | 50.00%    |
| 1998 | 1        | 1       | 1        | 33.33%    | 33.33%   | 33.33%    |
| 1999 | 0        | 2       | 1        | 0.00%     | 66.67%   | 33.33%    |
| 2000 | 0        | 3       | 5        | 0.00%     | 37.50%   | 62.50%    |
| 2001 | 0        | 0       | 2        | 0.00%     | 0.00%    | 100.00%   |
| 2002 | 0        | 0       | 8        | 0.00%     | 0.00%    | 100.00%   |
| 2003 | 0        | 0       | 11       | 0.00%     | 0.00%    | 100.00%   |
| 2004 | 0        | 1       | 18       | 0.00%     | 5.26%    | 94.74%    |
| 2005 | 0        | 1       | 14       | 0.00%     | 6.67%    | 93.33%    |
| 2006 | 0        | 1       | 21       | 0.00%     | 4.55%    | 95.45%    |
| 2007 | 1        | 6       | 24       | 3.23%     | 19.35%   | 77.42%    |
| 2008 | 0        | 2       | 21       | 0.00%     | 8.70%    | 91.30%    |
| 2009 | 0        | 1       | 15       | 0.00%     | 6.25%    | 93.75%    |
| 2010 | 5        | 6       | 27       | 13.16%    | 15.79%   | 71.05%    |
| 2011 | 1        | 5       | 14       | 5.00%     | 25.00%   | 70.00%    |
| 2012 | 3        | 10      | 15       | 10.71%    | 35.71%   | 53.57%    |
| 2013 | 0        | 4       | 4        | 0.00%     | 50.00%   | 50.00%    |
| 2014 | 2        | 5       | 6        | 15.38%    | 38.46%   | 46.15%    |
| 2015 | 0        | 2       | 4        | 0.00%     | 33.33%   | 66.67%    |
| 2016 | 0        | 18      | 5        | 0.00%     | 78.26%   | 21.74%    |

| Sum   | 15  | 69   | 219   | 4.95% | 22.77% | 72.28% |
Table 4

The absolute and relative number of shared bilateral relationships at mutual level (1985–2016).

| Year | ICEV-BEV | HEV-BEV | ICEV-HEV | ICEV-BEV% | HEV-BEV% | ICEV-HEV% |
|------|----------|---------|----------|-----------|----------|-----------|
| 1985 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1986 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1987 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1988 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1989 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1990 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1991 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1992 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1993 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1994 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1995 | 1        | 0       | 1        | 50.00%    | 0.00%    | 50.00%    |
| 1996 | 0        | 0       | 0        | 0.00%     | 0.00%    | 0.00%     |
| 1997 | 1        | 1       | 2        | 25.00%    | 25.00%   | 50.00%    |
| 1998 | 6        | 1       | 1        | 75.00%    | 12.50%   | 12.50%    |
| 1999 | 0        | 0       | 1        | 0.00%     | 0.00%    | 100.00%   |
| 2000 | 0        | 2       | 5        | 0.00%     | 28.57%   | 71.43%    |
| 2001 | 0        | 0       | 2        | 0.00%     | 0.00%    | 100.00%   |
| 2002 | 0        | 0       | 10       | 0.00%     | 0.00%    | 100.00%   |
| 2003 | 0        | 0       | 13       | 0.00%     | 0.00%    | 100.00%   |
| 2004 | 0        | 1       | 18       | 0.00%     | 5.26%    | 94.74%    |
| 2005 | 0        | 1       | 19       | 0.00%     | 5.00%    | 95.00%    |
| 2006 | 0        | 0       | 23       | 0.00%     | 0.00%    | 100.00%   |
| 2007 | 3        | 6       | 26       | 8.57%     | 17.14%   | 74.29%    |
| 2008 | 0        | 2       | 35       | 0.00%     | 5.41%    | 94.59%    |
| 2009 | 0        | 3       | 15       | 0.00%     | 16.67%   | 83.33%    |
| 2010 | 19       | 6       | 31       | 33.93%    | 10.71%   | 55.36%    |
| 2011 | 6        | 5       | 14       | 24.00%    | 20.00%   | 56.00%    |
| 2012 | 8        | 10      | 17       | 22.86%    | 28.57%   | 48.57%    |
| 2013 | 0        | 4       | 4        | 0.00%     | 50.00%   | 50.00%    |
| 2014 | 21       | 5       | 6        | 65.63%    | 15.63%   | 18.75%    |
| 2015 | 0        | 2       | 4        | 0.00%     | 33.33%   | 66.67%    |
| 2016 | 0        | 18      | 5        | 0.00%     | 78.26%   | 21.74%    |
| Sum  | 65       | 67      | 252      | 16.93%    | 17.45%   | 65.63%    |

Fig. 6 displays the most frequent bilateral relationships shaped among the parent organisations of two powertrain systems for the period 2008–2016. The related raw data lists all the organisations that collaboratively developed the joint patents shared between two powertrain systems over 2008–2016.

An Excel file is included in the Supplementary appendix of this article, which contains all the raw data related to the collaborating organisations at mutual level over 1985–1996, 1997–2007, and 2008–2016 as well as the entire period 1985–2016.

![Episode AB (1985-1996) Towards sustainable mobility](image_url)

Fig. 4. The most frequent shared bilateral relationships at mutual level for the period 1985–1996.
Regarding environmental results, we discovered that the shared bilateral relationships between the powertrain systems were developed in total around 435 unique subgroup-level IPC codes, of which 134 subgroup-level codes were related to environmentally friendly innovations.

Table 5 shows whether a subgroup-level IPC code at mutual level is green for the period 1985–1996.

Table 6 shows whether a subgroup-level IPC code at mutual level is green (or environmentally friendly)

![Fig. 5. The most frequent shared bilateral relationships at mutual level for the period 1997–2007.](image)

![Fig. 6. The most frequent shared bilateral relationships at mutual level for the period 2008–2016.](image)

| IPCs | green | freq. | IPCs | green | freq. | IPCs | green | freq. |
|------|-------|-------|------|-------|-------|------|-------|-------|
| B60K0006485 yes 1 | B60K000620 yes 3 | B60K000640 yes 1 |
| B60L00728 yes 1 | B60K000626 yes 3 | B60K0006448 yes 1 |
| B60L001114 yes 1 | B60L001112 yes 3 | F02B006100 no 1 |
| B60W001008 yes 1 | B60K000636 yes 2 | H02K007116 no 1 |
| B60W002000 yes 1 | B60K000640 yes 2 | H02K000718 no 1 |
| B60K001722 no 1 | B60K0006448 yes 1 |  |
| F02B007506 no 1 | F02N001104 no 1 |  |
| F02B006100 no 1 | F16F001518 no 1 |  |
| G05D001902 no 1 | H02K004902 no 1 |  |
| H02P001500 no 1 | H02P002900 no 1 |  |
| Total: 13 | Total: 20 | Total: 2 |
| Green: 5 | Green: 17 | Green: 2 |
| Non-green: 8 | Non-green: 3 | Non-green: zero |
for the period 1997–2007. Table 7 shows whether a subgroup-level IPC code at mutual level is green for the period 2008–2016. The raw data related to Table 5, Table 6, Table 7 contain the frequency and the environmental nature of all the subgroup-level IPC codes that have been used in the joint patents shared between two powertrain systems over 1985–1996, 1997–2007, and 2008–2016, respectively. An Excel file is included in the Supplementary appendix of this article, which lists the frequency and the environmental nature of all the subgroup-level IPC codes used at mutual level over 1985–1996, 1997–2007, and 2008–2016 as well as the entire period 1985–2016.

Regarding IPCs overlaps, Table 8 shows the frequency with which two powertrain systems share a group-level IPC code at mutual level for the period 1985–1996. Table 9 shows the frequency with which two powertrain systems share a group-level IPC code at mutual level for the period 1997–2007. Table 10 shows the frequency with which two powertrain systems share a group-level IPC code at mutual level for the period 2008–2016. The raw data related to Table 8, Table 9, Table 10 contain the frequency of all the group-level IPC codes that have been used in the joint patents shared between two powertrain systems over 1985–1996, 1997–2007, and 2008–2016, respectively. An Excel file is included in the Supplementary appendix of this article, which lists the frequency of all the group-level IPC codes used at mutual level over 1985–1996, 1997–2007, and 2008–2016 as well as the entire period 1985–2016.

Table 6
The frequency and the environmental nature of the subgroup-level IPC codes at mutual level for the period 1997–2007.

| IPCs       | green | freq. | IPCs       | green | freq. | IPCs       | green | freq. |
|------------|-------|-------|------------|-------|-------|------------|-------|-------|
| B60V002000 | yes   | 62    | B60V002000 | yes   | 10    | B60K000102 | yes   | 2     |
| B60V001006 | no    | 57    | B60K000620 | yes   | 8     | B60K000620 | yes   | 2     |
| B60K0006445| yes   | 55    | B60V001006 | no    | 8     | B60K000646 | yes   | 2     |
| B60V001008 | yes   | 52    | B60V001008 | yes   | 7     | B60L001112 | yes   | 2     |
| B60L001114 | yes   | 50    | B60V001026 | yes   | 7     | B60L001118 | yes   | 2     |
| F02D002902 | no    | 44    | F02D002902 | no    | 7     | B60W001008 | yes   | 2     |
| B60V001010 | no    | 41    | B60L001118 | yes   | 6     | B60W002000 | yes   | 2     |
| B60K000654 | yes   | 38    | B60L001114 | yes   | 5     | B60W001026 | no    | 2     |
| B60K000652 | yes   | 30    | B60K000646 | yes   | 4     | B60K000626 | yes   | 1     |
| B60K000644 | yes   | 29    | B60K000648 | yes   | 4     | B60K000628 | yes   | 1     |
| B60V001004 | no    | 27    | F02D002906 | no    | 4     | B60K000632 | yes   | 1     |
| F1H0066168 | no    | 23    | B60L001102 | yes   | 3     | B60K000636 | yes   | 1     |
| F1H00661684| no    | 22    | B60L001112 | yes   | 3     | B60K0006365| yes   | 1     |
| B60V001026 | yes   | 21    | H01M001044 | yes   | 3     | B60K0006442| yes   | 1     |
| F1H00661686| no    | 21    | H02J000700 | yes   | 3     | B60K000648 | yes   | 1     |
| F1H0066350 | no    | 21    | H02J000714 | yes   | 3     | B60K0006485| yes   | 1     |
| B60V001011 | no    | 19    | B60K000102 | yes   | 2     | B60K000654 | yes   | 1     |
| B60K001704 | no    | 17    | B60K000626 | yes   | 2     | B60L001114 | yes   | 1     |
| B60K000654 | yes   | 16    | B60K000628 | yes   | 2     | B60L001520 | yes   | 1     |
| F02D002900 | no    | 15    | B60K000640 | yes   | 2     | F01N000320 | yes   | 1     |
| B60V0010115| no    | 14    | B60K000642 | yes   | 2     | F02D004100 | yes   | 1     |
| F1H0066372 | yes   | 12    | B60K0006485| yes   | 2     | H02J000700 | yes   | 1     |
| B60K0006565| yes   | 11    | B60K0006543| yes   | 2     | H02J000714 | yes   | 1     |
| B60K00064 | yes   | 10    | B60K000654 | yes   | 2     | H02J000734 | yes   | 1     |
| F02D004500 | yes   | 10    | B60R001604 | yes   | 2     | B60H000100 | no    | 1     |
| B60V001000 | no    | 10    | B60K001704 | no    | 2     | B60H000132 | no    | 1     |
| F1H0065914 | no    | 10    | B60L000030 | no    | 2     | B60T000832 | no    | 1     |
| F1H0066102 | no    | 10    | B60W001002 | no    | 2     | B60V001006 | no    | 1     |
| F1H006340 | no    | 10    | B60W001004 | no    | 2     | B60V001018 | no    | 1     |
| B60K000102 | yes   | 9     | B60V001010 | no    | 2     | B60V001028 | no    | 1     |
| F1H0066104 | no    | 9     | B60V001018 | no    | 2     | F02B003700 | no    | 1     |
| B60V001018 | no    | 8     | B60V001030 | no    | 2     | F02B003716 | no    | 1     |
| ...        | ...   | ...   | ...        | ...   | ...   | ...        | ...   | ...   |
| Total: 1061|       |       | Total: 150 |       |       | Total: 47  |       |       |
| Green: 521 |       |       | Green: 94  |       |       | Green: 32  |       |       |
| Non-green: 540|    |       | Non-green: 56|      |       | Non-green: 15|    |       |
Table 7
The frequency and the environmental nature of the subgroup-level IPC codes at mutual level for the period 2008–2016.

| IPCs       | green freq. | IPCs       | green freq. | IPCs       | green freq. |
|------------|-------------|------------|-------------|------------|-------------|
| B60W002000 | yes 68      | B60W001008 | yes 21      | B60L001118 | yes 6       |
| B60W001006 | no 55       | B60W002000 | yes 20      | B60W002000 | yes 5       |
| B60K0006445| yes 52      | B60W001006 | no 18       | B60W001006 | no 4        |
| B60W001008 | yes 46      | B60L001118 | yes 11      | B60W001008 | yes 3       |
| B60L001114 | yes 45      | B60L001114 | yes 8       | H02J000714 | yes 3       |
| F02D002902 | no 40       | B60W002015 | yes 8       | B60L000900 | no 3        |
| F02D004500 | yes 23      | B60K000648 | yes 7       | B60W003018 | no 3        |
| B60K0006547| yes 20      | B60W003020 | no 7        | G06F000700 | no 3        |
| B60W001010 | no 16       | F02N001108 | no 6        | B60L001100 | yes 2       |
| B60K000648 | yes 15      | B60L001520 | yes 5       | B60R0016033| yes 2       |
| B60K000652 | yes 15      | B60W001002 | no 5        | H02J000700 | yes 2       |
| B60W001026 | yes 13      | B60W003018 | yes 5       | B60W001026 | yes 2       |
| B60K0006448| yes 12      | B60L000714 | yes 4       | G06F001700 | no 2        |
| B60W001004 | no 11       | B60L001718 | yes 4       | B60K000624 | yes 1       |
| F02D002906 | no 10       | B60L001112 | yes 4       | B60K0006445| yes 1       |
| B60K0006365| yes 9       | H02J000714 | yes 4       | B60K0006458| yes 1       |
| F16H001012 | no 9        | F02D002902 | no 4        | B60K0006547| yes 1       |
| F16H006350 | no 9        | B60K0006445| yes 3       | B60L001112 | yes 1       |
| B60K000640 | yes 8       | B60W001026 | yes 3       | B60L001114 | yes 1       |
| B60K000654 | yes 8       | B60W002013 | yes 3       | H01M000202 | yes 1       |
| F02D004114 | yes 8       | H02J000700 | yes 3       | H01M000210 | yes 1       |
| B60W001030 | no 8        | B60L000300 | no 3        | H01M000234 | yes 1       |
| B60W001002 | no 7        | B60L000900 | no 3        | H01M00010525| yes 1 |
| F02N001108 | no 7        | B60W001010 | no 3        | H01M0001046| yes 1       |
| B60K000102 | yes 6       | B60W001030 | no 3        | H02J000704 | yes 1       |
| B60L001118 | yes 6       | F02N001104 | no 3        | B60L000100 | no 1        |
| F16H00372 | yes 6       | F16H005704 | no 3        | B60L000102 | no 1        |
| B60K001704 | no 6        | B60K000620 | yes 2       | B60W001002 | no 1        |
| B60L000300 | no 6        | B60K000626 | yes 2       | B60W001011 | no 1        |
| B60W003018 | no 6        | B60K0006387| yes 2       | B60W0010115| no 1        |
| F02N001104 | no 6        | B60L000710 | yes 2       | B60W003019 | no 1        |
| F16H0061686| no 6        | B60L001100 | yes 2       | B60W005014 | no 1        |

Total: 937
Green: 501
Non-green: 436

Table 8
The most frequently shared used group-level IPC codes at mutual level for the period 1985–1996.

| IPCs         | freq. | IPCs         | freq. | IPCs         | freq. |
|--------------|-------|--------------|-------|--------------|-------|
| B60K0006     | 1     | B60K0006     | 11    | B60K0006     | 1     |
| B60L0007     | 1     | B60L0011     | 6     | B60W0010     | 1     |
| B60L0011     | 1     | H02K0007     | 2     |
| B60W0010     | 1     | F02B0061     | 1     |
| B60W0020     | 1     | F02B0075     | 1     |
| F02N0011     | 1     | F16F0015     | 1     |
| G05D0019     | 1     | H02K0049     | 1     |
| H02P0015     | 1     | H02P0029     | 1     |
| B60K0017     | 1     |

Total: 13
Total: 20
Total: 2
2. Experimental design, materials, and methods

We collected the patent data from Thomson Reuters’ online web-based platform Derwent Innovations Index [2], which is known as one of the largest and most prestigious patent platforms compiling data from over 80 global granting authorities [1]. Data collection occurred in November of 2018. We segmented the data into the three major automotive periods of ‘towards sustainable mobility’ (1985–1996), ‘towards hybridisation’ (1997–2007), and ‘towards mass commercialisation’ (2008–2016) [1]. We performed separate methodological steps for collecting and processing data at the individual and mutual levels.

2.1. Methodological steps at individual level

At individual level, we first extracted the patents related to each powertrain technological field from the DII platform using a combined search strategy of keywords IPC codes and keywords [1,3], shown in Table 11. Such strategy avoided any patents unrelated to the field [4–6]. We processed the data based on ‘patent families’ in order to avoid the multiple counting of the same inventions in different national patenting systems in the world [4,6]. We, additionally, ordered the extracted patents based on the earliest priority date in patent families. Because the priority date is the closest date to the finishing time of an invention that has been submitted for the first time to any of the world’ patenting systems [7], which can avoid including any additional lags, normally 18 months on average [5,7].

| Table 9 | The most frequently shared used group-level IPC codes at mutual level for the period 1997–2007. |
|---------|-------------------------------------------------|
| **ICEV-HEV** | **freq.** | **HEV-BEV** | **freq.** | **BEV-ICEV** | **freq.** |
| B60W00010 | 274 | B60W0010 | 35 | B60K0006 | 13 |
| B60K0006 | 247 | B60K0006 | 33 | B60W0010 | 7 |
| F16H0061 | 97 | B60L0011 | 18 | B60L0011 | 5 |
| F02D0029 | 66 | F02D0029 | 14 | H02J0007 | 3 |
| B60W0020 | 62 | B60W0020 | 10 | F02B0037 | 3 |
| B60L0011 | 56 | H02J0007 | 7 | H01G0011 | 2 |
| F16H0059 | 41 | H01M0010 | 5 | B60W0020 | 2 |
| F16H0063 | 32 | F02B0037 | 3 | B60H0001 | 2 |
| B60K0017 | 21 | B60H0001 | 2 | B60K0001 | 2 |
| F16H0003 | 21 | B60K0001 | 2 | B60T0008 | 1 |
| F02D0041 | 15 | B60K0017 | 2 | H02J0001 | 1 |
| F02N0011 | 13 | B60L0003 | 2 | H02M0003 | 1 |
| B60K0001 | 11 | B60R0016 | 2 | B60L0015 | 1 |
| F02D0045 | 10 | G01C0021 | 2 | F01N0001 | 1 |
| F16H0048 | 7 | B60K0025 | 1 | F02D0041 | 1 |
| B60L0015 | 7 | B60L0015 | 1 | F02M0035 | 1 |
| H02K0007 | 5 | B60T0008 | 1 | F02N0011 | 1 |
| B60T0007 | 4 | B60W0030 | 1 | | |
| B60T0008 | 4 | F01N0003 | 1 | | |
| F02D0017 | 4 | F02D0041 | 1 | | |
| F16H0057 | 4 | F02D0045 | 1 | | |
| F02B0037 | 4 | F02M0035 | 1 | | |
| F02M0025 | 4 | F02N0011 | 1 | | |
| B60L0003 | 3 | H01C0011 | 1 | | |
| B60L0009 | 2 | H02J0001 | 1 | | |
| F02B0039 | 2 | H02K0007 | 1 | | |
| F16H0045 | 2 | H02P0009 | 1 | | |
| B60H0001 | 2 | | | | |
| H02K0005 | 2 | | | | |

Total: 1061 Total: 150 Total: 47
In the second step, we verified the quality and appropriateness of our patents data by running a manual validity check for at least 5% of our total patents [4]. We considered a patent valid for our database if its claim could contain "... the categorized technology as well as the possibility of an automotive utilization" [4, p79]. Table 12 shows that our manual validity check at individual level reached a good performance as the quality result for each powertrain system was above 85.00%. In

| Table 10 | The most frequently shared used group-level IPC codes at mutual level for the period 2008–2016. |
| --- | --- |
| **ICEV-HEV** | **freq.** | **HEV-BEV** | **freq.** | **BEV-ICEV** | **freq.** |
| B60K0006 | 190 | B60W0010 | 62 | B60W0010 | 12 |
| B60W0010 | 169 | B60W0020 | 39 | B60L0011 | 10 |
| B60W0020 | 73 | B60L0011 | 27 | H01M0010 | 8 |
| B60L0011 | 57 | B60K0006 | 23 | H02J0007 | 6 |
| F02D0029 | 56 | B60W0030 | 17 | B60W0020 | 5 |
| F02D0041 | 37 | B60L0007 | 12 | B60W0030 | 4 |
| F16H0061 | 36 | F02N0011 | 12 | B60K0006 | 4 |
| F02D0045 | 23 | H01M0008 | 10 | H01M0002 | 3 |
| F02N0011 | 15 | H01M0010 | 10 | B60L0009 | 3 |
| F16H0059 | 15 | B60L0015 | 7 | G06F0007 | 3 |
| F16H0063 | 14 | H02J0007 | 7 | C25D0011 | 3 |
| B60W0030 | 12 | B60L0003 | 5 | G06F0017 | 2 |
| F16H0003 | 11 | F02D0029 | 5 | B60L0001 | 2 |
| B60K0017 | 9 | B60W0050 | 4 | B60R0016 | 2 |
| B60K0001 | 8 | F16H0057 | 4 | F02N0011 | 2 |
| B23K0026 | 7 | H01M0004 | 4 | H02M0001 | 1 |
| B60L0003 | 7 | B60L0001 | 3 | H01F0037 | 1 |
| B60L0009 | 6 | B60L0009 | 3 | H02J0001 | 1 |
| H02J0007 | 6 | F02D0041 | 3 | B60W0050 | 1 |
| B60W0050 | 6 | F16H0061 | 3 | H02P0009 | 1 |
| F01N0003 | 6 | H01M0002 | 3 | H01F0038 | 1 |
| B60L0015 | 5 | B60K0017 | 2 | F16H0057 | 1 |
| G06F0019 | 4 | B60N0002 | 2 | H01F0027 | 1 |
| F02D0017 | 4 | B60R0016 | 2 | G05D0003 | 1 |
| F02M0025 | 4 | B6OT0008 | 2 | F16H0061 | 1 |
| G06F0017 | 4 | F02B0039 | 2 | G05D0001 | 1 |
| F02B0053 | 4 | G06F0007 | 2 | F02B0039 | 2 |
| F16H0057 | 4 | H02P0009 | 2 | G05D0003 | 1 |
| F02M0026 | 4 | B60K0026 | 1 | G06F0017 | 1 |
| Total:937 | Total:300 | Total:80 |

In the second step, we verified the quality and appropriateness of our patents data by running a manual validity check for at least 5% of our total patents [4]. We considered a patent valid for our database if its claim could contain "... the categorized technology as well as the possibility of an automotive utilization" [4, p79]. Table 12 shows that our manual validity check at individual level reached a good performance as the quality result for each powertrain system was above 85.00%. In

| Table 11 | Search terms of keywords and IPC codes used at individual level [1,3]. |
| --- | --- |
| **Technological field** | **Search query** |
| Individual level | ICEV-related patents | TAB=("internal combustion engine" OR "ic engine" OR "diesel engine") AND (vehicle* or car or automobile*); AND (PRDS>=19850101 AND PRDS<=20161231) AND IC=(F01* OR B60* OR F02B* OR F02D* OR F02F* OR F02M* OR F02N* OR F02P*); |
| | HEV-related patents | TAB=("hybrid electric vehicle" OR "hybrid vehicle" OR "hybrid propulsion" OR "hybrid car" OR "hybrid automobile" OR "hybrid electric car") AND (PRDS>=19850101 AND PRDS<=20161230) AND IC=(F02* OR F16H* OR B60K006* OR B60W020 OR B60L0071* OR B60L000720); |
| | BEV-related patents | TAB=("electric vehicle" OR "electric car" OR "electric automobile") AND (battery AND (vehicle* or car or automobile*)); AND (PRDS>=19850101 AND PRDS<=20161230) AND IC=(H02k* OR H01 M* OR B60L011* OR B60L003* OR B60L015* OR B60K00101* OR B60W001008 OR B60W001024 OR B60W001026); |
the last step, we selected the patents that were jointly shared between two or more organisations or assignees, i.e. joint patents. Note that we counted only those organisations that were shown by the Thomson Reuters platform as ultimate parents. A joint patent shows whether the property rights of the invention are jointly assigned or owned by two or more organisations [8]. We took into account all the possible relationships in a joint patent by splitting any trilateral, quadrilateral or higher connections into bilateral relationships [1,9]. For instance, a patent co-assigned by Mitsubishi, Toyota, and Denso contains the three bilateral connections of Toyota- Mitsubishi, Toyota-Denso, and Mitsubishi-Denso.

2.2. Methodological steps at mutual level

At mutual level, we first extracted the patents shared between two powertrain technological fields from the DII platform using a different combined search strategy of IPC codes and keywords [1,3], shown in Table 13. We similarly processed the data based on ‘patent families’ and ‘priority date’.

In the second step, we verified their quality and appropriateness by another manual validity check for 5% of the total shared patents. As Table 14 shows, the quality at mutual level reached a good performance as well. In the third step, while we selected only those patents that were jointly assigned to two or more organisations (i.e. shared joint patents), we again split any trilateral, quadrilateral or higher connections in a joint patent into bilateral relationships (i.e. shared bilateral relationships). In the fourth step, we explored the overlaps between the powertrain systems in terms of environmental innovations and knowledge domains by extracting the IPC

### Table 12
Validity check of data at individual level (1985–2016) [1].

| Technological field | Granted patents | Validity check |
|---------------------|-----------------|----------------|
|                     | Absolute | Relative | Sample size | Quality |
| Individual level    |           |         |             |         |
| ICEV                | 49,154   | 62.43%  | 2460        | 87.25%  |
| HEV                 | 10,888   | 13.83%  | 545         | 89.80%  |
| BEV                 | 18,690   | 23.74%  | 940         | 88.25%  |
| Total               | 78,732   | 100.00% | 3945        | 87.84%  |

### Table 13
Search terms of keywords and IPC codes used at mutual level [1,3].

| Technological field       | Search query                                                                 |
|---------------------------|------------------------------------------------------------------------------|
| ICEV-HEV related patents  | TAB=(("internal combustion engine" OR "ic engine" OR "diesel engine") AND ("hybrid electric vehicle" OR "hybrid vehicle" OR "hybrid propulsion" OR "hybrid car" OR "hybrid automobile" OR "hybrid electric car") AND (vehicle* or car or automobile*) AND (PRDS>=19850101) AND PRDS<=(20161231)) AND IC=(F01* OR B60* OR F16H × OR F02B* OR F02D* OR F02F* OR F02 M* OR F02 N* OR F02P* OR B60K006* OR B60W020 OR B60L00071* OR B60L000720) |
| ICEV-BEV related patents  | TAB=(("internal combustion engine" OR "ic engine" OR "diesel engine") AND ("electric vehicle" OR "electric car" OR "electric automobile") AND (vehicle* or car or automobile*) AND (PRDS>=19850101) AND PRDS<=(20161230)) AND IC=(F01* OR B60* OR F02B* OR F02D* OR F02F* OR F02 M* OR F02 N* OR F02P* OR H02K* OR H01 M* OR B60L011* OR B60L003* OR B60L015* OR B60K00101* OR B60W001008 OR B60W001024 OR B60W001026) |
| BEV-HEV related patents   | TAB=(("electric vehicle" OR "electric car" OR "electric automobile") AND battery AND (vehicle* or car or automobile*) AND ("hybrid electric vehicle" OR "hybrid vehicle" OR "hybrid propulsion" OR "hybrid car" OR "hybrid automobile" OR "hybrid electric car") AND (PRDS>=19850101) AND PRDS<=(20161230)) AND IC=(F16H* OR H02K* OR H01 M* OR B60L011* OR B60L003* OR B60L015* OR B60K00101* OR B60W001008 OR B60W001024 OR B60W001026 OR B60K006* OR B60W020 OR B60L00071* OR B60L000720) |
codes that were used within the shared joint patents. We used IPC codes for two reasons. First, IPC codes are able to manifest the knowledge domains overlaps between patents because the IPC codes (knowledge domains) used in a patent do not exist solely for the development of the intended invention but can be exploited and utilised for other inventions [10]. Second, IPC codes are able to manifest whether innovations built in an invention are environmentally friendly (or green) [1,11]. Note that for the environmental innovations overlap we took advantage of subgroup-level IPC codes (e.g. B60W-010/10) as they can distinguish green innovations from non-green ones. The IPC green inventory adopted by Ref. [11] was used, which is a combination of the WIPO’s IPC Green Inventory and the OECD’s list of environmentally-sound technologies (EST). For the knowledge domain overlap, we reduced the extracted subgroup-level IPC codes to group-level IPC codes (e.g. B60W-010) as they can provide more general but useful information about the technical or knowledge domains of an invention [1,12].

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Conflict of Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data
Supplementary data to this article can be found online at https://doi.org/10.1016/j.dib.2019.105017.

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