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Working Paper Series

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February 2024

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Papatya Duman[*] and Claus-Jochen Haake[†]

February 29, 2024

Abstract

We investigate whether the recently approved reforms of the apportionment of parliamentary seats to parties in the German Bundestag affects the parties' political influence measured by power indices. We find that under neither reform the underlying simple game, which describes the possibilities to form governments, remains unchanged and as a result the Shapley-Shubik and the Banzhaf index are unaltered. As a consequence, the major change from the reforms is the size reduction in the Bundestag by currently 106 legislators to 630.

1 Introduction

In the current German parliament, the *Bundestag*, there are 736 members, making it the second-largest parliament in the world. According to the laws, there should be a minimum of 598 members, but due to the excessive use of overhang mandates (*Überhangsmandate*) and compensatory

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mandates (*Ausgleichsmandate*), an additional 138 representatives are working in Berlin. Recognizing that this configuration of the parliament undermines the proportional election system, the German Federal Constitutional Court decided in 2012 that the federal election law needed to be revised. Subsequently, in 2020 and 2023, the German Bundestag implemented two reforms to the election system. Especially the most recent decision from March 2023, approved by the majority of government parties, triggered widespread discussions on the consequences. With this reform, overhang and compensatory mandates, as well as the base mandate clause (*Grundmandateklausel*), have been abolished, and an upper limit of 630 for the number of representatives in the parliament was introduced. As a further new implication, the winner of an electoral constituency is no longer guaranteed a seat in the Bundestag.

Despite the debate on whether proportionality is well-reflected, one may want to examine the consequences in terms of potential majorities in the parliament. When considering the power of a party generated by the possibilities of being part of a government, the question of which party might be relatively more influential is a significant one. It falls within the realm of cooperative game theory. Power indices, such as the Banzhaf index (Banzhaf, 1965) or Shapley-Shubik index (Shapley and Shubik, 1954), are tools that help us in measuring and comparing the "governmental" powers of parties. These indices only take into account a party's possibility to be part of a government, i.e., they ignore the exact numbers of seats.

In this paper, we address the question by how much or whether at all power indices would have changed, if the recent reforms have or had not or would already have been in place. Thus, we explore the impact of the reforms on political influence measured by power indices. What we find is that a reform does not change anything in terms of power and can therefore be considered as not harmful. From an economic point of view, the positive effect is a cost reduction that results from the reduction in legislators.

The next section gives a coarse overview over the German electoral system, Section 3 introduces cooperative games and power indices. Sections 4.1 and 4.2 display the power indices in the 20th (since 2021) and 19th (2017–2021) Bundestag and range in the results. Section 5 concludes.

2   The German Electoral System

Here we briefly sketch the German electoral system to understand the foundation for the application of power indices in Section 4. For a more

detailed discussion see Bochsler (2023) or Grotz and Schroeder (2023).

Germany has a mixed-member proportional representation system for its elections. The parliament *Bundestag*, which hosts (at least) 598 legislators, is elected for a four-years term. The seats are distributed among the sixteen federal states based on the number of voters in each state. Each voter has two votes: a constituency vote (first vote, *Erststimme*) and a party list vote (second vote, *Zweitstimme*). The first votes are used to directly elect 299 legislators in single-member constituencies, which are therefore called direct mandates (*Direktmandate*). The second votes serve to allocate the number of seats for a party, which is approximately proportional to the share of second votes for that party. This is divided into two steps. First, an apportionment to federal states is determined and then the final allocation of parties' seats in the Bundestag is calculated by the the Sainte-Laguë/Schepers (Sainte-Laguë, 1910) method. This procedure is in place since 2009 and succeeded the methods of Hare/Niemeyer (1985-2005) and d'hondt (1949-1983). If a party wins more seats in a state than its second votes would entitle it to overhang seats (*Überhangsmandate*), other parties receive compensatory seats (*Ausgleichsmandate*). Overhang seats are calculated at the state level. More seats are added to compensate for overhang seats between different states, and more seats than needed are added to compensate for overhang at the national level to avoid negative vote weighting so that it is guaranteed that more second votes do not trigger fewer seats. As a result, in the past two legislatures the number of members in the Bundestag increased significantly to 736 at present, 138 of which are overhang and compensatory seats.

The number of a party's seats is determined by the proportion of second votes that this party received. However, only parties with a second votes share of at least 5 percent, for which a minority rule applies[1], or which won at least three direct mandates from the constituency votes are represented in the Bundestag. The latter arrangement is called the 3 constituency seat exception (*Grundmandatsklausel, GMK*).

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[1]There are only four national or ethnic minorities that the German government recognizes. Two of these minority are politically represented by the *Südschleswigsche Wählerverband* (SSW), with their ancestral settlement region located in the state Schleswig-Holstein. The minority party alone must obtain the amount of electoral votes necessary to secure a mandate. In 2021, over 40,000 votes were needed to make this happen. The SSW was granted a seat in the Bundestag after this quota was met.

3 Power Indices

In this section we briefly describe the two most widely used power indices to attribute influence or power in a decision body to the involved players or parties.

By $N := \{1, \ldots, n\}$ we denote the set of parties or players. A coalition is a subset of parties, i.e. $\mathcal{N} := \{S \mid S \subseteq N\}$ denotes the set of coalitions. A simple game v is determined by the coalitions that are winning, i.e., which have enough power to win an election. By $\mathcal{W}(v)$ denote the set of winning coalitions.[2] Given the seat distribution (in the Bundestag) by a vector $m = (m_1, \ldots, m_n)$ so that m_i is party i's number of seats, and a majority threshold of α, we can derive a simple game v by requiring that a coalition is winning if and only if the sum of its members' seats exceeds the threshold α.[3]

To measure the influence of a party within a parliament, i.e., within the set of all parties, one can either focus on the proportionality principle in the sense that more seats imply more power, or factor in the possibilities to form winning coalitions. Power indices are designed to pursue the latter route as they rest on the underlying simple game. More precisely, the indices we discuss next, the Shapley-Shubik index and the Banzhaf index, take into account how often a party is pivotal for a winning coalition that means removing the party from the coalition renders its status from winning to losing, i.e., $S \in \mathcal{W}(v)$ and $S \setminus \{i\} \notin \mathcal{W}(v)$.

The *Shapley-Shubik index (SSI)* for party i in a simple game v is defined by

$$SSI_i(v) := \sum_{S \in \mathcal{N}: S \in \mathcal{W}(v), S \setminus \{i\} \notin \mathcal{W}(v)} \frac{(n - |S|)! \, (|S| - 1)!}{n!}$$

where $|S|$ is the number of members in coalition S. While the Shapley-Shubik index considers all $n!$ ways in which players can be ordered and counts how often a party is pivotal on average in the coalition of successors, the *Banzhaf index (BI)* attributes to party i the share of the coalitions, for which i is pivotal:

$$BI_i(v) := \frac{|\{S \in \mathcal{N} : S \in \mathcal{W}(v), S \setminus \{i\} \notin \mathcal{W}(v)\}|}{2^{n-1}}.$$

Since the sum of Banzhaf indices across parties need not equal 1, we define

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[2] In cooperative game theory, v typically is a function $v : \mathcal{N} \to \{0, 1\}$ that assigns a value $v(S) = 1$ to any winning coalition S and zero otherwise with the convention $v(\emptyset) = 0$.

[3] For an absolute majority, α is the smallest integer being equal to or exceeding $(\frac{1}{2} \sum_{i=1}^{n} m_i) + 1$.

the normalized version for party i, $\overline{BI}_i(v)$ by

$$\overline{BI}(v) := \frac{BI_i(v)}{\sum_{i=1}^{n} BI_i(v)}.$$

Thereby, the normalized Banzhaf index keeps the same relation between any two parties as in the non-normalized version.

Two remarks on the application of power indices have to be made. First, by considering the simple game that stems from the seat distribution and a majority threshold, the indices ignore parties' preferences or dislikes over potential partners in a coalition. Second, the consideration of a simple game implicitly assumes a party discipline in the sense that all members (seats) of a party vote in the party's interest. At least for the election of the chancellor, who is elected by the Bundestag, it is not too implausible that this discipline can be taken for granted.

4 Power Indices in the Bundestag

To assess the implications of the reforms that affect the size of the Bundestag, we compare the $\overline{BI}$ and SSI for the current Bundestag to the indices when a reform has or has not been in place. We start with the results from the elections in 2021 and 2017 and then present the indices.

4.1 The 20th Bundestag (2021 – present) and current reforms

The 20th German Bundestag was elected on September 26, 2021 and is the current parliament of Germany with 736 seats. Those seats have been distributed across 7 parties: *Social Democratic Party of Germany* (SPD), *Christian Democratic Union/Christian Social Union* (CDU/CSU), *Free Democratic Party* (FDP), *Alliance 90/The Green Party* (GRÜNE), *Alternative for Germany* (AfD), *the Left* (Die Linke) and *South Schleswig Voters' Association* (SSW). Of the 46,442,023 valid second votes, SPD received 25.74%, CDU/CSU 24.07%, FDP 11.46%, GRÜNE 14.75%, AfD 11.32%, Die Linke 4.89% and SSW 0.12%. Although Die Linke was below the 5% threshold, the party received three direct mandates and was therefore eligible to send legislators to the Bundestag. Table 1 summarizes the results.

The last column displays the percentages of second votes relative to the total of second votes of those parties in the Bundestag. It is worth mentioning that the proportionality reflected by the final seat distribution is very

Party	Direct mandates	Party mandates	Total mandates	Relative share of total mandates	Relative percentage second votes
SPD	121	85	206	27.99%	25.74%
CDU/CSU	143	54	197	26.77%	24.07%
FDP	0	92	92	12.50%	11.46%
GRÜNE	16	102	118	16.03%	14.75%
AfD	16	67	83	10.34%	11.32%
Die Linke	3	36	39	5.30%	4.89%
SSW	0	1	1	0.14%	0.12%
Total	299	437	736	100%	91.38%

Table 1: The seat distribution in the 20th Bundestag

close to the proportionality in the second votes. It is apparent that this is clearly easier to satisfy the larger the size of the parliament.

The minimum number of seats required to form a government is $736/2 + 1 = 369$. Coalitions with a total seat count surpassing this number are winning coalitions, and the smallest coalitions with this characteristic are minimal winning coalitions. The simple game that is generated by the distribution of seats can be represented by its minimal winning coalitions. For this, we enumerate the seven parties by P1,...,P7 with P1=SPD, P2=CDU/CSU, P3=FDP, P4=GRÜNE, P5=AfD, P6=Die Linke, P7=SSW. There are 7 minimal coalitions, namely

$$\{P1, P2\}, \{P1, P3, P4\}, \{P1, P3, P5\}, \{P1, P4, P5\}, \{P2, P3, P4\},$$

$$\{P2, P3, P5\} \text{ and } \{P2, P4, P5\}.$$

It should be noted that all parties except Die Linke and SSW are members in at least one minimal winning coalition, which has the effect that these parties are never pivotal for a coalition and will therefore be attributed a SSI or $\overline{BI}$ of zero.

Inspecting Table 1 one sees that the usual size of 598 seats was by far exceeded. After the election in 2017 the size of the parliament was 709 and already above the bar. In 2020 a reform was approved by the Bundestag that helped to reduce the number of parliamentary seats by limiting the number of balancing mandates. Without this reform the current Bundestag would have 787 members, i.e., an increase of 51 (see Table 2 and A). However, the 2020 reform, due to the presence of more parties in the Bundestag

and the phenomenon where parties with relatively more direct mandates received lower shares of second votes, was not deemed effective enough to significantly reduce the number of seats.

As a result the government proposed and finally approved a further reform of the electoral law with two basic cornerstones. First the base mandate clause (GMK-clause) was abolished, which means that winning three or more direct mandates does no longer qualify for being present in the Bundestag. And second, the size is limited to 630 seats by law, which in effect means that not all winners in the 299 constituencies will automatically hold a seat in the Bundestag. We term this reform the 2023 reform.

We question which consequences in terms of power indices would have resulted, if these reforms have already been or have not been in place. More precisely, we compare the current distribution to the situation (A) without the 2020 reform (w/o 2020), (B) with the 2020 reform and without the GMK clause (w/o GMK) and (C) with the 2020 and 2023 reforms in place (w 2023). Thereby, we took the number of first and second votes from 2021 and applied the apportionment rules behind the scenarios. Table 2 displays the resulting distributions of seats.

Party	Current	(A) w/o 2020	(B) w/o GMK	(C) w 2023
SPD	206	221	206	189
CDU/CSU	197	208	197	175
FDP	92	99	92	82
GRÜNE	118	127	118	106
AfD	83	89	83	77
Die Linke	39	42	3	-
SSW	1	1	1	1
Total	736	787	700	630

Table 2: The seat distribution in the 20th Bundestag and its hypothetical versions

Before we present the power indices for the different scenarios, we have a look at their minimal winning coalitions. P6 (Die Linke) does not appear in any of the minimal winning coalitions of the fictive Bundestag in (A), (B), or (C). As a consequence, the set of minimal winning coalitions is the same in all three scenarios and amounts to

$$\{P1, P2\}, \{P1, P3, P4\}, \{P1, P3, P5\}, \{P1, P4, P5\}, \{P2, P3, P4\},$$

$\{P2, P3, P5\}$ and $\{P2, P4, P5\}$.

Table 3 shows the normalized Banzhaf index in the current Bundestag and for all three alternative scenarios.

Party	Current	(A) w/o 2020	(B) w/o GMK	(C) w 2023
SPD	16/56	16/56	16/56	16/56
CDU/CSU	16/56	16/56	16/56	16/56
FDP	8/56	8/56	8/56	8/56
GRÜNE	8/56	8/56	8/56	8/56
AfD	8/56	8/56	8/56	8/56
Die Linke	0	0	0	0
SSW	0	0	0	0

Table 3: Banzhaf Power Index for the 20th Bundestag

It is not a surprising result that the outcome that shows the parliament's power distribution remaining steady, as the minimal winning coalitions in each case are the same, i.e., the underlying simple game is the same. Consequently, we obtain this result also for the Shapley-Shubik index, which is displayed in Table 4.

Party	Current	(A) w/o 2020	(B) w/o GMK	(C) w 2023
SPD	9/30	9/30	9/30	9/30
CDU/CSU	9/30	9/30	9/30	9/30
FDP	4/30	4/30	4/30	4/30
GRÜNE	4/30	4/30	4/30	4/30
AfD	4/30	4/30	4/30	4/30
Die Linke	0	0	0	0
SSW	0	0	0	0

Table 4: Shapley-Shubik Power Index for the 20th Bundestag

Summarizing we find that under any reform the power indices (SSI and $\bar{B}I$) for the 20th Bundestag remain unchanged.

4.2 The 19th Bundestag (2017 – 2021)

The 19th German Bundestag was elected on September 24, 2017 and in office between October 24, 2017 and October 26, 2021. 46,515,492 German

citizens casted valid votes. The Bundestag had 709 seats that were divided among 6 parties with the following shares of second votes: SPD (20.51%), CDU/CSU (32.93%), FDP (10.75%), GRÜNE (8.94%), AfD (12.64%) and Die Linke (9.24%). Table 5 summarizes the results.

Party	Direct mandates	Party mandates	Total mandates	Relative share of total mandates	Relative percentage second votes
SPD	59	94	153	21.58%	20.51%
CDU/CSU	231	15	246	34.70%	32.93%
FDP	0	80	80	11.28%	10.75%
GRÜNE	1	66	67	9.45%	8.94%
AfD	3	91	94	13.26%	12.64%
Die Linke	5	64	69	9.73%	9.24%
Total	299	410	709	100%	95%

Table 5: The seat distribution in the 19th Bundestag

We calculated the alternative seat distributions for the two scenarios with the 2020 reform in place (w 2020) and both reforms in place (w 2023) and display the results in Table 6. As all parties exceed the 5 percent electoral threshold in this election, the GMK-clause has no effect and is therefore omitted.

Party	Current	(D) w 2020	(E) w 2023
SPD	153	151	135
CDU/CSU	246	246	218
FDP	80	79	70
GRÜNE	67	66	62
AfD	94	93	84
Die Linke	69	68	61
Total	709	703	630

Table 6: The seat distribution in the 19th Bundestag and its hypothetical versions

The simple game is different from the one that is generated after the 2021 election. We have eleven minimal winning coalitions:

$\{P1, P2\}, \{P2, P3, P4\}, \{P2, P3, P5\}, \{P2, P3, P6\}, \{P2, P4, P5\}, \{P2, P4, P6\},$

$\{P2, P5, P6\}, \{P1, P3, P4, P5\}, \{P1, P3, P4, P6\}, \{P1, P3, P5, P6\}$, and $\{P1, P4, P5, P6\}$.

Besides the coalition of SPD and CDU/CSU, which actually formed the government, one can either group the SPD with three of the remaining four parties or group the CDU/CSU with two of the remaining parties, showing that there is a fundamental difference in power between P1 and P2. The simple games derived from the three different variants are equal so that the power indices do not differ, either. The $\overline{BI}$ and the SSI are listed in Table 7.

Party	Current	w 2020	w 2023
SPD	5/28	5/28	5/28
CDU/CSU	11/28	11/28	11/28
FDP	3/28	3/28	3/28
GRÜNE	3/28	3/28	3/28
AfD	3/28	3/28	3/28
Die Linke	3/28	3/28	3/28
Party	Current	w 2020	w 2023
SPD	2/10	2/10	2/10
CDU/CSU	4/10	4/10	4/10
FDP	1/10	1/10	1/10
GRÜNE	1/10	1/10	1/10
AfD	1/10	1/10	1/10
Die Linke	1/10	1/10	1/10

Table 7: Banzhaf Index (left) and the Shapley-Shubik index (right) for the 19th Bundestag

Therefore, also for the 19th Bundestag applying either reform would not have changed parties' power indices.

5 Discussion of the results and update

When comparing the power indices that emerge after the 2017 and 2020 elections in either of the versions, one can see no difference in power. Therefore, one can say that the reforms that either have been installed or will be installed do not trigger a significant change in the possibilities to form majorities, i.e., changes in the simple game.

The most striking difference (after the implementation of the 2023 Reform) is that the party "Die Linke" would not be present in the current Bundestag. The major change, however, is that the number of members of the parliament will significantly be reduced and therefore saves economic resources. The German taxpayers' association (*Bund der Steuerzahler*) estimates savings of 340 million Euro per legislation period[4].

The functioning of the 2020 reform can be seen in Table 2. Without this reform, the current Bundestag would have 51 additional members. Also from Table 2 we can see that cancellation of the GMK clause alone would have limited the number of seats by only 36 instead of 106 with the 2023 reform in place.

We close with an update. On December 6, 2023 Die Linke lost its status of a parliamentary party after 10 legislators left it. As a parliamentary group, the members also lost their votes in parliamentary committees. As this party was not present in the set of minimal winning coalitions, our results remain unaffected.

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[4]See https://www.zeit.de/politik/deutschland/2023-03/bundestag-wahlrecht-reform-bund-der-steuer-zahler-einsparen (in German, last access 2024/02/23).

A Computations

A.1 The 20th Bundestag

- **Minimal Winning Coalitions in the 20th Bundestag:** Coalitions capturing an absolute majority include the followings:

$$\{P1, P2\}(403 seats), \{P1, P3, P4\}(416 seats), \{P1, P3, P5\}(381 seats),$$

$$\{P1, P4, P5\}(407 seats), \{P2, P3, P4\}(407 seats), \{P2, P3, P5\}(372 seats)$$

$$\text{and } \{P2, P4, P5\}(398 seats).$$

If one of the parties is not part of the coalition, these coalitions lose the majority required to form a government. Other coalitions, excluding these, either do not have 369 seats or even if some parties are not part of the coalition, they still have 369 seats.

- **The seat distribution of the 20th Bundestag:** As shown in Table 8, the number of seats parties obtained from the combination of second votes and first votes is as follows:

$$P1 - 170 seats, P2 - 167(122 + 45) seats, P3 - 76 seats, P4 - 94 seats,$$

$$P5 - 69 seats, P6 - 32 seats, P7 - 1 seat.$$

This way, 609 seats are allocated, but the shares of the parties in the second votes in this distribution are inconsistent with the actual shares. To equalize these shares as much as possible, 127 more seats are allocated to the parties, and the parliament reaches its final form with 736 seats:

$$P1 - 206 seats, P2 - 197(152 + 45) seats, P3 - 92 seats, P4 - 118 seats,$$

$$P5 - 83 seats, P6 - 39 seats, P7 - 1 seat.$$

Those additional seats are calculated via the Sainte-Lague/Schepers procedure. The suitable divisor here is 57899. The valid votes given to the parties are divided by this number and rounded.

- **Situation A (w/o 2020):** If the divisor above is replaced with 53996, then the total number of seats becomes 787. The divisor is smaller here as there is no restriction on the overhang mandates. That restriction is introduced by the 2020 Reform. Minimal Winning Coalitions in this situation are

$$\{P1, P2\}(429 seats), \{P1, P3, P4\}(447 seats), \{P1, P3, P5\}(409 seats),$$

$\{P1, P4, P5\}(437seats), \{P2, P3, P4\}(434seats), \{P2, P3, P5\}(396seats)$

and $\{P2, P4, P5\}(424seats)$.

- **Situation B (w/o GMK):** Die Linke has seats in the 20th Bundestag by utilizing the GMK (see Table8). In situation B, die Linke cannot have more than 3 (the number of the direct mandates) representatives in the Bundestag. Table 9 shows how the parties share 607 seats:

$P1 - 178seats, P2 - 177(132 + 45)seats, P3 - 78seats, P4 - 100seats,$

$P5 - 73seats, P7 - 1seat.$

By the application of the compensatory mandates and with 3 Linke representatives, the size of the Bundestag reaches 700 seats:

$P1 - 206seats, P2 - 197(152 + 45)seats, P3 - 92seats, P4 - 118seats,$

$P5 - 83seats, P6 - 3seats, P7 - 1seat.$

- **Situation C (w 2023):** Table 10 shows how 630 seats are allocated between the parties.

- **Power Indices for the 20th Bundestag :**

The underlying simple game for each case is the same in which there are 64 winning coalitions. $P1$ and $P2$ are critical in 16 of those coalitions, $P3 - P5$ are critical in 8 of them, and $P6 - P7$ are never critical. Then, $BI_1 = BI_2 = \frac{16}{64}$, $BI_3 = BI_4 = BI_5 = \frac{8}{64}$ and $BI_6 = BI_7 = \frac{0}{64}$. This implies $\overline{BI} = (\frac{16}{56}, \frac{16}{56}, \frac{8}{56}, \frac{8}{56}, \frac{8}{56}, 0, 0)$.

The coalitions for which $P1$ and $P2$ are critical have different sizes: one 2-player, eight 3-player, fourteen 4-player, eight 5-player and one 6-player coalitions. Hence, $SSI_1 = SSI_2 = \frac{5!}{7!} + 8\frac{4!2!}{7!} + 13\frac{3!3!}{7!} + 8\frac{2!4!}{7!} + \frac{5!}{7!} = \frac{9}{30}$. $P3 - P5$ are critical for four 3-player, eight 4-player and four 5-player coalitions, this implies $SSI_3 = SSI_4 = SSI_5 = 4\frac{4!2!}{7!} + 8\frac{3!3!}{7!} + 4\frac{2!4!}{7!} = \frac{4}{30}$. As $P6 - P7$ are never critical, $SSI = (\frac{9}{30}, \frac{9}{30}, \frac{4}{30}, \frac{4}{30}, \frac{4}{30}, 0, 0)$.

Table 8: The number of representatives calculated without adding compensation seats in the 20th Bundestag

	Population (2021)	Landessitze (2021)	SPD					CDU					CSU					FDP					Grün					AFD					Linke					SSW				
			LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM
Schleswig-Holstein	2922005	22	6	8	7	8	2	5	2	4	4	0	0	0	0	0	0	3	0	2	2	0	4	1	3	3	0	2	0	1	1	0	1	0	1	1	0	1	0	1	1	0
Mecklenburg-Vorpommern	1611160	13	4	6	5	6	2	2	0	1	1	0	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	2	1	2	2	0	1	0	1	1	0	0	0	0	0	0
Hamburg	1853935	13	4	4	4	4	0	2	0	1	1	0	0	0	0	0	0	2	0	1	1	0	1	2	3	3	0	1	0	1	1	0	1	0	1	1	0	0	0	0	0	0
Niedersachsen	8027031	59	21	22	22	22	1	15	8	12	12	0	0	0	0	0	0	6	0	3	3	0	10	0	5	5	0	5	0	3	3	0	2	0	1	1	0	0	0	0	0	0
Bremen	676463	5	2	2	2	2	0	1	0	1	1	0	0	0	0	0	0	1	0	1	1	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brandenburg	2537868	20	7	10	9	10	3	3	0	2	2	0	0	0	0	0	0	2	0	1	1	0	1	0	1	1	0	4	2	3	3	0	1	0	1	1	0	0	0	0	0	0
Sachsen-Anhalt	2169253	17	5	4	5	5	0	4	3	4	4	0	0	0	0	0	0	2	0	1	1	0	1	0	1	1	0	3	2	3	3	0	2	0	1	1	0	0	0	0	0	0
Berlin	3677472	24	6	4	5	5	0	4	3	4	4	0	0	0	0	0	0	3	0	2	2	0	6	3	5	5	0	2	0	1	1	0	3	2	3	3	0	0	0	0	0	0
Nordrhein-Westfalen	17924591	127	40	30	35	35	0	35	30	33	33	0	0	0	0	0	0	15	0	8	8	0	22	4	13	13	0	9	0	5	5	0	5	0	3	3	0	0	0	0	0	0
Sachsen	4043002	32	7	1	4	4	0	6	4	5	5	0	0	0	0	0	0	4	0	2	2	0	3	0	2	2	0	10	10	10	10	1	3	1	2	2	0	0	0	0	0	0
Hessen	6295017	43	13	14	14	14	1	11	7	9	9	0	0	0	0	0	0	6	0	3	3	0	7	1	4	4	0	4	0	2	2	0	2	0	1	1	0	0	0	0	0	0
Thüringen	2108863	16	4	3	4	4	0	3	1	2	2	0	0	0	0	0	0	2	0	1	1	0	1	0	1	1	0	3	1	2	2	0	2	0	1	1	0	0	0	0	0	0
Rheinland-Pfalz	4106485	30	10	8	9	9	0	8	7	8	8	0	0	0	0	0	0	4	0	2	2	0	4	0	2	2	0	3	0	2	2	0	1	0	1	1	0	0	0	0	0	0
Bayern	13176989	93	20	0	10	10	0	0	0	0	0	0	34	45	40	45	11	11	0	6	6	0	15	1	8	8	0	10	0	5	5	0	3	0	2	2	0	0	0	0	0	0
Baden-Württemberg	11124642	77	18	1	10	10	0	21	33	27	33	12	0	0	0	0	0	13	0	7	7	0	14	4	9	9	0	8	0	4	4	0	3	0	2	2	0	0	0	0	0	0
Saarland	982348	7	3	4	4	4	1	2	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Total:	598		170	121	152	max{170,152}=170	10	122	98	120	max{122,120}=122	12	34	45	45	max{34,45}=45	11	76	0	42	max{76,42}=76	0	94	16	59	max{94,59}=94	0	69	16	46	max{69,46}=69	1	32	3	21	max{32,21}=32	0	1	0	0	max{1,0}=1	0

LS: the number of seats obtained in a state proportional to the second votes
DM: the number of direct mandates obtained in a state
MW: average of LS and DM in a state
Min: maximum of DM and MW in a state, the guaranteed minimum number of seats
UM: the additional seats required to reach DM when DM>LS
Total (guaranteed) seats: 609
Total direct mandates: 299
Total overhang mandates: 34

	Population (2021)	Landessitze	SPD LS	SPD DM	SPD MW	SPD Min	SPD UM	CDU LS	CDU DM	CDU MW	CDU Min	CDU UM	CSU LS	CSU DM	CSU MW	CSU Min	CSU UM	FDP LS	FDP DM	FDP MW	FDP Min	FDP UM	Grün LS	Grün DM	Grün MW	Grün Min	Grün UM	AfD LS	AfD DM	AfD MW	AfD Min	AfD UM	SSW LS	SSW DM	SSW MW	SSW Min	SSW UM
Schleswig-Holstein	2922005	22	7	8	8	8	1	5	2	4	4	0	0	0	0	0	0	3	0	2	2	0	4	1	3	3	0	2	0	1	1	0	1	0	1	1	0
Mecklenburg-Vorpommern	1611160	13	5	6	6	6	1	3	0	2	2	0	0	0	0	0	0	2	0	1	1	0	1	0	1	1	0	3	0	2	2	0	0	0	0	0	0
Hamburg	1853935	13	4	4	4	4	0	2	0	1	1	0	0	0	0	0	0	2	0	1	1	0	4	2	3	3	0	1	0	1	1	0	0	0	0	0	0
Niedersachsen	8027031	59	21	22	22	22	1	16	8	12	12	1	0	0	0	0	0	7	0	4	4	0	10	1	5	5	0	5	0	3	3	0	0	0	0	0	0
Bremen	676463	5	2	2	2	2	0	1	0	1	1	0	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Brandenburg	2537868	20	7	10	9	10	3	4	0	2	2	0	0	0	0	0	0	2	0	1	1	0	2	0	1	1	0	5	2	3	3	0	0	0	0	0	0
Sachsen-Anhalt	2169253	17	5	4	5	5	0	5	3	4	4	0	0	0	0	0	0	2	0	1	1	0	1	0	1	1	0	4	2	3	3	0	0	0	0	0	0
Berlin	3677472	24	7	4	6	6	0	5	3	4	4	0	0	0	0	0	0	3	0	2	2	0	7	3	5	5	0	2	0	1	1	0	0	0	0	0	0
Nordrhein-Westfalen	17924591	127	41	30	36	36	0	37	30	34	34	0	0	0	0	0	0	16	0	8	8	0	23	4	14	14	0	10	0	5	5	0	0	0	0	0	0
Sachsen	4043002	32	8	1	5	5	0	7	4	6	6	0	0	0	0	0	0	4	0	2	2	0	3	0	2	2	0	10	10	10	10	0	0	0	0	0	0
Hessen	6295017	43	14	14	14	14	0	11	7	9	9	0	0	0	0	0	0	6	0	3	3	0	8	1	5	5	0	4	0	2	2	0	0	0	0	0	0
Thüringen	2108863	16	5	3	4	4	0	3	7	2	2	0	0	0	0	0	0	2	0	1	1	0	1	0	1	1	0	5	4	5	5	0	0	0	0	0	0
Rheinland-Pfalz	4106485	30	10	8	9	9	0	9	7	8	8	0	0	0	0	0	0	4	0	2	2	0	4	0	2	2	0	3	0	2	2	0	0	0	0	0	0
Bayern	13176989	93	20	0	10	10	0	0	0	0	0	0	35	45	40	45	10	11	0	6	6	0	16	1	9	9	0	10	0	5	5	0	0	0	0	0	0
Baden-Württemberg	11124642	77	19	1	10	10	0	22	33	28	33	11	0	0	0	0	0	13	0	7	7	0	15	4	10	10	0	8	0	4	4	0	0	0	0	0	0
Saarland	982348	7	3	4	4	4	1	2	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0
Total: Seats: 598			178	121	155	155	7	132	98	123	123	11	35	45	40	45	10	78	0	43	43	0	100	16	63	63	0	73	16	48	48	0	1	0	1	1	0
			max[178,155]=178					max[132,123]=132					max(34,45)=45					max[78,43]=78					max[100,63]=100					max[73,48]=73					max[1,1]=1				

LS: the number of seats obtained in a state proportional to the second votes
DM: the number of direct mandates obtained in a state
MW: average of LS and DM in a state
Min: maximum of DM and MW in a state, the guaranteed minimum number of seats
UM: the additional seats required to reach DM when DM>LS
Total (guaranteed) seats: 607
Total direct mandates: 296
Total overhang mandates: 30

Table 9: The number of representatives calculated without adding compensation seats in the 20th Bundestag and without the implementation of the GMK rule.

	Population (2021)	Landessitze	SPD		CDU		CSU		FDP		Grün		AFD		SSW	
			LS	DM	LS	DM	LS	DM	LS	DM	LS	DM	LS	DM	LS	DM
Schleswig-Holstein	2922005	23	7	8	5	2	0	0	3	0	5	1	2	0	1	0
Mecklenburg-Vorpommern	1611160	13	5	6	3	0	0	0	1	0	1	0	3	0	0	0
Hamburg	1853935	13	4	4	2	0	0	0	2	0	4	2	1	0	0	0
Niedersachsen	8027031	63	23	22	17	8	0	0	7	0	11	0	5	0	0	0
Bremen	676463	5	2	2	1	0	0	0	1	0	1	0	0	0	0	0
Brandenburg	2537868	21	8	10	4	0	0	0	2	0	2	0	5	0	0	0
Sachsen-Anhalt	2169253	18	6	4	5	3	0	0	2	0	1	0	4	2	0	0
Berlin	3677472	26	8	6	5	3	0	0	3	0	7	3	3	0	0	0
Nordrhein-Westfalen	17924591	134	43	30	39	30	0	0	17	0	24	4	11	0	0	0
Sachsen	4043002	33	8	1	7	4	0	0	4	0	4	1	10	10	0	0
Hessen	6295017	45	14	14	12	7	0	0	7	0	8	1	4	0	0	0
Thüringen	2108863	17	5	3	4	1	0	0	2	0	1	0	5	4	0	0
Rheinland-Pfalz	4106485	31	11	8	9	7	0	0	4	0	4	0	3	0	0	0
Bayern	13176989	99	21	0	0	0	38	45	12	0	17	1	11	0	0	0
Baden-Württemberg	11124642	81	20	1	22	33	0	0	14	0	16	4	9	0	0	0
Saarland	982348	8	4	4	2	0	0	0	1	0	0	0	1	0	1	0
Total:		630	189	123	137	98	38	45	82	0	106	17	77	16	1	0

LS: the number of seats obtained in a state proportional to the second votes
DM: the number of direct mandates obtained in a state
Total (guaranteed) seats: 630
Total direct mandates: 299

Table 10: The number of representatives calculated in the 20th Bundestag after the application of the 2023 Reform.

A.2 The 19th Bundestag

- **Minimal Winning Coalitions in the 19th Bundestag:** Coalitions capturing an absolute majority include the followings:

  $\{P1, P2\}(399seats), \{P2, P3, P4\}(393seats), \{P2, P3, P5\}(420seats),$

  $\{P2, P3, P6\}(395seats), \{P2, P4, P5\}(407seats), \{P2, P4, P6\}(382seats),$

  $\{P2, P5, P6\}(409seats), \{P1, P3, P4, P5\}(394seats), \{P1, P3, P4, P6\}(369seats),$

  $\{P1, P3, P5, P6\}(396seats),$ and $\{P1, P4, P5, P6\}(383seats).$

  If one of the parties is not part of the coalition, these coalitions lose the majority required to form a government. Other coalitions, excluding these, either do not have 355 seats or even if some parties are not part of the coalition, they still have 355 seats.

- **The seat distribution of the 19th Bundestag:** As shown in Table 11, the number of seats parties obtained from the combination of second votes and first votes is as follows:

  $P1 - 131seats, P2 - 246(200 + 46)seats, P3 - 65seats, P4 - 57seats,$

  $P5 - 83seats, P6 - 59seats.$

  This way, 641 seats are allocated, but the shares of the parties in the second votes in this distribution are inconsistent with the actual shares. To equalize these shares as much as possible, 68 more seats are allocated to the parties, and the parliament reaches its final form with 709 seats:

  $P1 - 153seats, P2 - 246(200 + 46)seats, P3 - 80seats, P4 - 67seats,$

  $P5 - 94seats, P6 - 69seats.$

  Those additional seats are calculated via the Sainte-Lague/Schepers procedure. The suitable divisor here is 62394. The valid votes given to the parties are divided by this number and rounded.

- **Situation w 2020:** If the divisor above is replaced with 63070, then the total number of seats becomes 703. The divisor is greater here as there is a restriction on the overhang mandates. That restriction is

introduced by the 2020 Reform. Minimal Winning Coalitions in this situation are

$$\{P1, P2\}\,(397seats), \{P2, P3, P4\}\,(391seats), \{P2, P3, P5\}\,(418seats),$$

$$\{P2, P3, P6\}\,(393seats), \{P2, P4, P5\}\,(405seats), \{P2, P4, P6\}\,(380seats),$$

$$\{P2, P5, P6\}\,(407seats), \{P1, P3, P4, P5\}\,(389seats), \{P1, P3, P4, P6\}\,(364seats),$$

$$\{P1, P3, P5, P6\}\,(391seats), \text{ and } \{P1, P4, P5, P6\}\,(378seats).$$

- **Situation w 2023:** Table 12 shows how 630 seats are allocated between the parties.

- **Power Indices for the 20th Bundestag :**

  The underlying simple game for each case is the same in which there are 32 winning coalitions. $P1$ is critical in 10 of those coalitions, $P2$ is critical in 22 of those coalitions, and $P3 - P6$ are critical in 6 of them. Then, $BI_1 = \frac{10}{32}$, $BI_2 = \frac{22}{32}$, and $BI_3 = BI_4 = BI_5 = BI_6 = \frac{6}{32}$. This implies $\overline{BI} = \left(\frac{5}{28}, \frac{11}{28}, \frac{3}{28}, \frac{3}{28}, \frac{3}{28}, \frac{3}{28}\right)$.

  $P1$ is critical for one 2-player, four 3-player, four 4-player and one 5-player coalitions; i.e., $SSI_1 = \frac{4!}{6!} + 4\frac{3!2!}{6!} + 4\frac{2!3!}{6!} + \frac{4!}{6!} = \frac{2}{10}$. $P2$ is critical for one 2-player, ten 3-player, ten 4-player and one 5-player coalitions; i.e., $SSI_2 = \frac{4!}{6!} + 10\frac{3!2!}{6!} + 10\frac{2!3!}{6!} + \frac{4!}{6!} = \frac{4}{10}$. Last but not least, $P3 - P6$ are critical for three 3-player and three 4-player coalitions, this implies $SSI_3 = SSI_4 = SSI_5 = SSI_6 = 3\frac{3!2!}{6!} + 3\frac{2!3!}{6!} = \frac{1}{10}$. Thus, $SSI = \left(\frac{2}{10}, \frac{4}{10}, \frac{1}{10}, \frac{1}{10}, \frac{1}{10}, \frac{1}{10}\right)$.

	Population (2017)	Landessitze	SPD					CDU					CSU					FDP					Grün					AFD					Linke				
			LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM	LS	DM	MW	Min	UM
Schleswig-Holstein	2922005	22	5	1	3	3	0	7	10	9	10	3	0	0	0	0	0	3	0	2	2	0	1	0	2	2	0	2	0	2	2	0	2	0	1	1	0
Mecklenburg-Vorpommern	1611160	13	2	0	1	1	0	4	6	5	6	2	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	3	0	2	2	0	2	0	1	1	0
Hamburg	1835935	12	3	5	4	5	2	3	1	2	2	0	0	0	0	0	0	1	0	1	1	0	2	0	1	1	0	1	0	1	1	0	2	0	1	1	0
Niedersachsen	8027031	59	17	14	16	16	0	21	16	19	19	0	0	0	0	0	0	6	0	3	3	0	5	0	3	3	0	6	0	3	3	0	4	0	2	2	0
Bremen	676463	5	1	2	2	2	1	1	0	1	1	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	0	1	0	1	1	0	1	0	1	1	0
Brandenburg	2537868	20	4	1	3	3	0	6	9	8	9	3	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	4	0	2	2	0	4	0	2	2	0
Sachsen-Anhalt	2169253	17	3	0	2	2	0	5	9	7	9	4	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	4	0	2	2	0	3	0	2	2	0
Berlin	3677472	24	5	3	4	4	0	6	4	5	5	0	0	0	0	0	0	2	0	1	1	0	3	1	2	2	0	3	0	2	2	0	5	4	5	5	0
Nordrhein-Westfalen	17924591	128	35	26	31	31	0	43	38	41	41	0	0	0	0	0	0	17	0	9	9	0	10	0	5	5	0	13	0	7	7	0	10	0	5	5	0
Sachsen	4043002	32	4	0	2	2	0	9	12	11	12	3	0	0	0	0	0	3	0	2	2	0	2	0	1	1	0	9	3	6	6	0	5	1	3	3	0
Hessen	6295017	43	11	5	8	8	0	14	17	16	17	3	0	0	0	0	0	5	0	3	3	0	4	0	2	2	0	5	0	3	3	0	4	0	2	2	0
Thüringen	2108863	17	3	0	2	2	0	5	8	7	8	3	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	4	0	2	2	0	3	0	2	2	0
Rheinland-Pfalz	4106485	30	8	1	5	5	0	11	14	13	14	3	0	0	0	0	0	3	0	2	2	0	2	0	1	1	0	4	0	2	2	0	2	0	1	1	0
Bayern	13176989	93	15	0	8	8	0	0	0	0	0	0	39	46	43	46	7	10	0	5	5	0	10	0	5	5	0	13	0	7	7	0	6	0	3	3	0
Baden-Württemberg	11124642	76	13	0	7	7	0	27	38	33	38	11	0	0	0	0	0	10	0	5	5	0	11	0	6	6	0	10	0	5	5	0	5	0	3	3	0
Saarland	982348	7	2	1	2	2	0	2	3	3	3	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0
Total:	598		131	59		101	3	164	185		194	36	39	46		46	7	65	0		38	0	57	1		33	0	83	3		47	0	59	5		35	0
Seats:				max{131,101}=131					max{164,194}=194					max{39,46}=46					max{65,38}=65					max{57,33}=57					max{83,47}=83					max{59,35}=59			

LS: the number of seats obtained in a state proportional to the second votes
DM: the number of direct mandates obtained in a state
MW: average of LS and DM in a state
Min: maximum of DM and MW in a state, the guaranteed minimum number of seats
UM: the additional seats required to reach DM when DM>LS
Total (guaranteed) seats: 641
Total direct mandates: 299
Total overhang mandates: 46

Table 11: The number of representatives calculated without adding compensation seats in the 19th Bundestag

	Population (2017)	Landessitze	SPD LS	SPD DM	CDU LS	CDU DM	CSU LS	CSU DM	FDP LS	FDP DM	Grün LS	Grün DM	AFD LS	AFD DM	Linke LS	Linke DM
Schleswig-Holstein	2922005	23	5	1	8	10	0	0	3	0	3	0	2	0	2	0
Mecklenburg-Vorpommern	1611160	13	2	0	4	6	0	0	1	0	1	0	3	0	2	0
Hamburg	1853935	13	3	5	4	1	0	0	1	0	2	0	1	0	2	0
Niedersachsen	8027031	63	18	14	23	16	0	0	6	0	6	0	6	0	4	0
Bremen	676463	5	1	2	1	0	0	0	0	0	1	0	1	0	1	0
Brandenburg	2537868	21	4	1	6	9	0	0	2	0	1	0	4	0	4	0
Sachsen-Anhalt	2169253	18	3	0	6	9	0	0	1	0	1	0	4	0	3	0
Berlin	3677472	26	5	3	6	4	0	0	3	0	4	1	3	0	5	4
Nordrhein-Westfalen	17924591	134	36	26	46	38	0	0	18	0	11	0	13	0	10	0
Sachsen	4043002	33	4	0	9	12	0	0	3	0	2	0	9	3	6	1
Hessen	6295017	45	11	5	14	17	0	0	5	0	5	0	6	0	4	0
Thüringen	2108863	17	3	0	5	8	0	0	1	0	1	0	4	0	3	0
Rheinland-Pfalz	4106485	31	8	1	12	14	0	0	3	0	2	0	4	0	2	0
Bayern	13176989	99	16	0	0	0	42	46	11	0	10	0	13	0	7	0
Baden-Württemberg	11124642	81	14	0	29	38	0	0	11	0	12	0	10	0	5	0
Saarland	982348	8	2	1	3	3	0	0	1	0	0	0	1	0	1	0
Total:		630	135	59	176	185	42	46	70	0	62	1	84	3	61	5

LS: the number of seats obtained in a state proportional to the second votes
DM: the number of direct mandates obtained in a state
Total (guaranteed) seats: 630
Total direct mandates: 299

Table 12: The number of representatives calculated in the 19th Bundestag after the application of the 2023 Reform.

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2024-02	Papatya Duman Claus-Jochen Haake	Size Reduction Reform in German Parliament: a game theoretic analysis of power indices in the Bundestag
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